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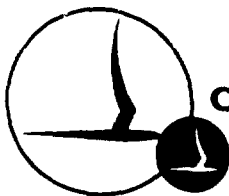
RADIOLOGICAL TARGET ANALYSIS PROCEDURES

Prepared for:
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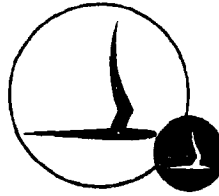
Report No. VP-1699-G-1

June 28, 1963



CORNELL AERONAUTICAL LABORATORY, INC.

OF CORNELL UNIVERSITY, BUFFALO 21, N. Y.



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BUFFALO 21, NEW YORK

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OFFICE OF CIVIL DEFENSE
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"This report represents the author's views, which in general are in harmony with the technical criteria of the Office of Civil Defense. However, a preliminary evaluation by OCD indicates that further study of the subject area is desirable."

OCT 18 1963

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"Qualified requestors may obtain copies of this report
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The principal value of a study of reclamation procedures is to aid civil defense planners to estimate, before an attack, the effects of various operational procedures in dealing with various forms of the threat, and thus to develop contingency plans and standard operational procedures which can be implemented expeditiously after an attack, conditioned by measurements of the actual situation. Thus, the emphasis herein was on identifying the important estimates required and developing computational procedures for producing them, recognizing that situations will vary from city-to-city as well as will the effort devoted to planning activities.

The approach to the problem was to study decontamination as an activity over a large populated area, with the object of finding the implications of the large operation for small areas. For small areas, analytical and computational procedures were developed to handle detailed factors such as structural shielding due to buildings, process programming, and personnel scheduling. Results are available for a number of simple examples to demonstrate the techniques that have been developed.

RESULTS AND RECOMMENDATIONS

The following accomplishments were made in the research:

Simple techniques have been demonstrated in a local area with the result that a populated area of 700,000 people exposed to a nuclear attack outside of the area can be restored in roughly 10 days after the attack. (Chapter IV)

2) Analysis was conducted of scheduling the entry of operators into a radioactive field. Techniques similar to dynamic programming were applied, with the result that for certain circumstances specific optimal start times can be specified. (Chapter VII)

3) Computational procedures and computer programs have been evolved for testing procedures in simulated environments. A hypothetical case was considered to test the mathematics and the computer program. (Chapter VI)

4) Substantial analysis was performed on the shielding effect of structures in a target area. The following types of target areas were analyzed:

- a) Single building on flat plane
- b) Residential complex
- c) Plaza
- d) Downtown city

A computer program is available for evaluating a complex downtown city area. This can now be applied rather easily to abstracted areas from the center of any major city. (Chapter VIII)

The research program was slanted towards the development of analytical and computational tools rather than the solution of some special problems.

The following follow-on work is now in order, either as a continuation of this research, or as a separate project:

- 1) Apply the computational tools to the analysis of a variety of target areas of each type to develop knowledge of variations and average effects of structural shielding in target areas. This information should be generalized.
- 2) Continue with analysis of several specified typical attack situations, postulating in each case the effort required, and applying available equipment to each situation.
- 3) Study the effect of equipment distribution in a populated area. Postulate optimal placement of equipment and optimal pre-fallout positioning.
- 4) Study the reclamation of specific places of high priority such as power stations, water plants, and hospitals.
- 5) Examine the management-communication structure of the reclamation system with the purpose of specifying their requirements for efficient action of the reclamation system.
- 6) Study numerically process ordering techniques applicable to small areas in which structures appear.

- 7) Develop a simple method for scheduling the entry and exit of operating personnel into and out of radioactive areas.

The above-mentioned items are logical follow-ups for the work already done. The long range objective is to provide methods of putting together good reclamation systems. The remaining work should follow the procedures set out in the present report, namely to have or develop a clear idea of a large unit system, and to postulate subsystems and suboperations to fit in with the major unit.

III. RESEARCH OBJECTIVES

INTRODUCTION

After a nuclear attack the intensity and duration of fallout in many areas may necessitate extremely long stays in shelter for the general population, unless the contaminant is removed. Considerable work has already been done on the physical methods of decontamination. The immediate purpose of the work reported herein is to extend knowledge on the operational aspects of this problem. The ultimate objective of this work is to develop sufficient knowledge for the design of optimum decontamination systems and the determination of optimal decontamination procedures. Also it is to help in assessing the equipment and facilities needed, on a nationwide basis, to perform the job adequately after nuclear attack. Finally, the information is to lead to a set of specific instructions to civil defense personnel in all localities on how to perform large scale decontamination after an attack.

THE DECONTAMINATION PROBLEM

Basically the decontamination problem stems from the following factors.

- a) Radiation is harmful to humans, even in small amounts.
- b) A nuclear attack, especially a massive one, will inundate the country with fallout so dangerous that life will be in jeopardy for those who don't proceed to shelter and stay there for long periods of time.

- c) There are no easy methods for removing or neutralizing contaminants to the extent that it is harmless.

These three points are only the beginning of the problem. It is further complicated by the following factors:

- a) There are not enough fallout shelters for everyone, and those which are available are not uniformly distributed according to population.
- b) The weapon explosion will destroy many of the shelters making them useless against fallout.
- c) Very many people will be killed and injured as a result of the bomb attack, making it necessary for others to perform rescue work just when they need to be in shelter.
- d) The extreme sound and light of the weapon explosion may drive masses of people out of their wits with the result that they will run around aimlessly, rather than to a safe place.*
- e) Many people will be away from their families at the moment of attack. They will be motivated to rejoin their families when their best move is to take shelter. Even after they are in shelter they will still want to join their families as soon as possible.

* Von Greyerz, Psychology of Survival

- f) The attack will have disrupted the utilities; water, power and gas will most certainly be off if the explosion has occurred nearby. These utilities will be essential for many people who have not prepared themselves for this emergency. Consequently these utilities have to be restored somehow while fallout is still a serious danger.
- g) Emergency facilities, particularly hospitals, fire departments, and police will face unusual difficulty because of the emergency. Their load is hard in peace time. In an attack, therefore, people operating these facilities cannot take cover; instead they will be on extra duty. Something must be done to reduce the radiation hazard where they need to operate.
- h) Equipment for decontamination is in limited supply, in addition personnel can operate this equipment for limited periods of time (in intensely radioactive areas time available may not be enough even to get started). Hence plans must be available to put equipment and operating personnel to best use.

These are the highlights of the problem. There are many more detailed factors. In general there is an extremely complex and painful conflict to resolve. Whatever way things will be done, many lives and much property will be lost. It is very important, therefore to be prepared to do the very best that can be done both in terms of selecting the optimal combination of activities and adhering to an optimal schedule so that losses will be minimized.

TECHNICAL BACKGROUND

Substantial research on decontamination methods has been conducted by the U. S. Naval Radiological Defense Laboratory, San Francisco, California and others, with the first experiments starting in 1948. At first the research was concerned with the removal of simulated contaminant by such obvious methods as street-sweeping and firehosing. Later on the research was concerned with the decontamination of many types of surfaces and numerous methods of removal. The total experimental effect to date is sufficient for postulating specific plans for organized decontamination of large postulated areas. There is, of course, more refined work that can be done, but this can now be defined better by highlighting the missing details after an attempt at optimizing decontamination operations under a variety of operating conditions.

Briefly, previous work can be highlighted in the following chronological order. (The list is not exhaustive.)

<u>Date of Report</u>	<u>Type of Experimental Work</u>
1948	Street sweeper and firehose on roofs and pavements
1948	Handsweeping and firehose on roofs and pavements
1952	Land and vehicle decontamination
1957	Decontamination effectiveness on pavements and building surfaces
1957	Decontamination of land
1958	Evaluation of countermeasures and operational procedures
1959	Decontamination of land Dry decontamination methods
1960	Wet decontamination methods

<u>Date of Report</u>	<u>Type of Experimental Work</u>
1961	Roof washdown
1962	System plan for industrial complex
1962	System experiments on target complex containing 2-story apartment buildings
1962	Comprehensive report on up-to-date knowledge on reclamation and radiological countermeasures by Dr. C. F. Miller

This sequence follows the usual course of a research of this importance. At first the idea of decontamination was tested on a moderate scale. Success with those experiments led to more comprehensive research. As the process progressed, decontamination systems were envisaged and after careful research was conducted to find and choose best methods of accomplishing reclamation, some tests were conducted to observe how a complete system would indeed perform.

The present work is part of an effort to postulate optimal systems and procedures to accomplish reclamation. The analysis is heavily based on Dr. C. F. Miller's publication "Fallout and Radiological Countermeasures".

BASIC KNOWLEDGE REQUIRED FOR ANALYTICAL WORK

The information required for the formulation of operational plans is as follows:

- 1) Nature of post attack fallout situation, including radiation intensity, the area involved and the effect on the general public.

- 2) Physical methods of combating fallout, includes all countermeasure from sheltering to fallout removal.
- 3) Constraints within which fallout removal operations can take place and criteria for selecting best procedures.
- 4) Effects of environment on radiation intensity patterns
- 5) Effects of operational procedures on radiation patterns (e. g. ordering of processes)
- 6) Effects of timing and scheduling of operations
- 7) Resources available for the synthesis of operational facilities. This includes not only the existing facilities, but the ability of various localities for getting additional equipment
- 8) Priorities of some areas and facilities for decontamination with respect to other areas.
- 9) Existing distribution (or feasible optimal distribution) of resources
- 10) Effects of failure, of components essential to operations, including the failure of utilities
- 11) Interactions with other post attack operations

Previous work already provides substantial knowledge for items 1 and 2 and some information is available for items 3 and 4; the rest is relatively undefined.

PURPOSE AND SCOPE OF THIS RESEARCH

The original objective of the research was to translate available basic information into operational plans for decontamination. However, after the research got underway, it was learned that very much basic information essential for operations research was still missing. Hence it became the objective to contribute to the basic methods and information needed to prepare the way for the accomplishment of the original objective. The work of this report is oriented to deal especially with items 3, 4, 5 and 6 of the preceding section. The accomplishments shown in the report are the following:

- 1) An example is given to show how simple techniques and available knowledge can be applied to form a skeleton plan for the decontamination of a city if the fallout situation is given. Chapter IV
- 2) Some criteria are given for systems optimization. Chapter V
- 3) Techniques for modelling systems component operations are discussed. Chapter V
- 4) An analytical treatment of scheduling for minimization of dosage is presented. Chapter VII
- 5) Environmental effects (effects of complex structures) on radiation fields is dealt with for a variety of target areas. The emphasis is on the realization of computer methods and computer programs. Examples are shown on what can be done and the programs are now available for general application. Chapter VIII

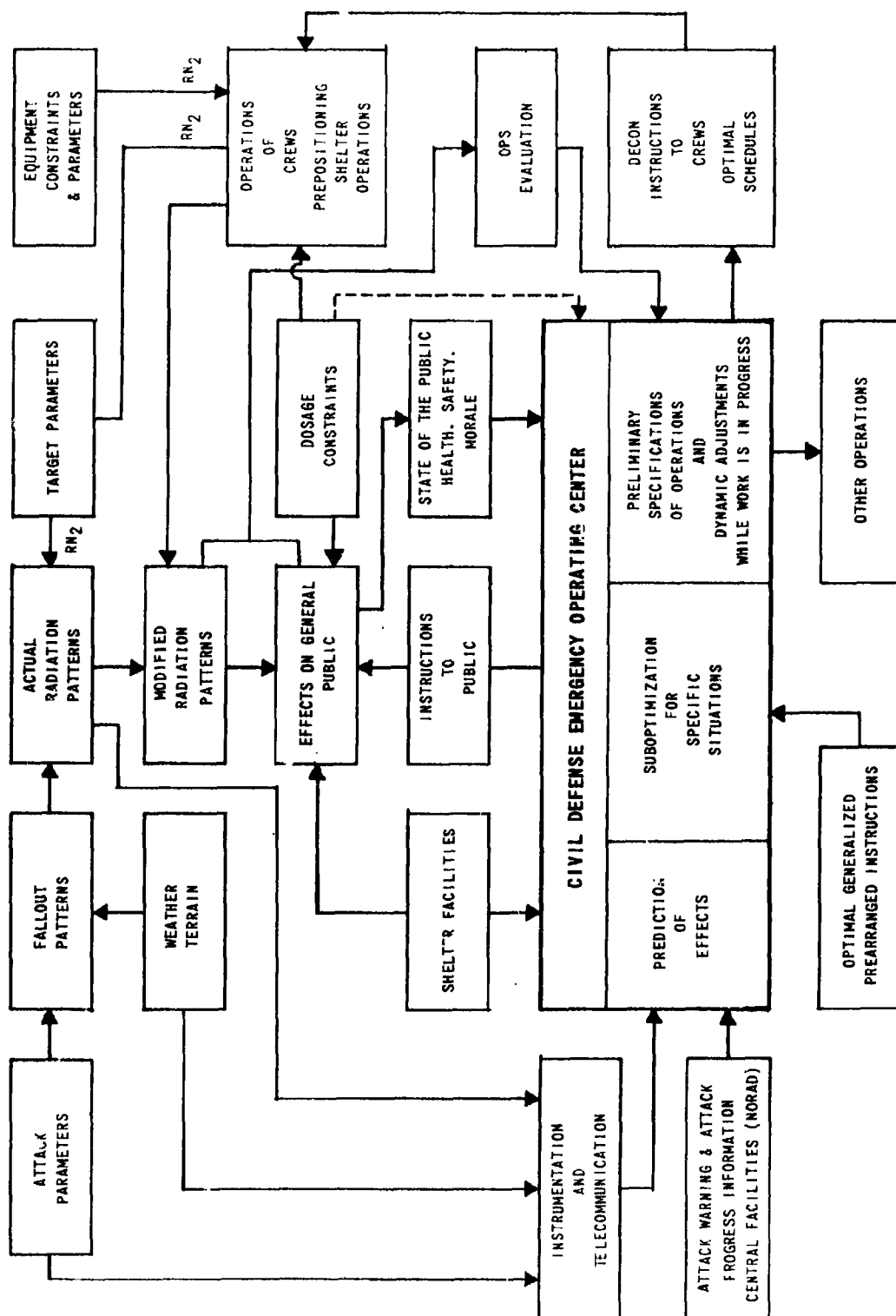
IV. SIMPLE DECONTAMINATION SYSTEMS FOR LARGE POPULATED AREAS

A BRIEF DESCRIPTION OF A DECONTAMINATION SYSTEM

Figure 1 represents the dominant components of a decontamination system and their interrelationships. Essentially, there are four major components:

- 1) Civil Defense Emergency Operating Center
- 2) The Decontamination Machinery
- 3) The Target Area
- 4) The Operating Personnel

In Figure 1 the attack parameters are shown as the primary input information to which the rest of the system responds. The fallout is shown as a function of the attack, the weather and the terrain. The instrumentation of the system transmits all this information to the Civil Defense Emergency Operating Center, where it is used to predict the emergency situation and to plan for it. The center is in control of public activities and over its countermeasure facilities including the decontamination operations equipment and personnel. The operating center's responsibility is to supervise reclamation operations in such a way that the process moves along efficiently and rapidly while the general public is kept in shelter. As areas become available for habitation, the operating center allows rehabilitation, taking care that the general public will not be overexposed. The reclamation and rehabilitation process is continued until the emergency is over.



ASSUMPTIONS FOR SIMPLIFYING THE GENERAL DECONTAMINATION PROBLEM

It is obvious that an analysis which treats the problem in all its complexity is too difficult. To gain a foothold on the problem, it is essential to simplify it until it is in a sufficiently tractable form; to solve the simple problem, and then to make consecutive adjustments after reintroducing the most important difficulties one by one. This procedure holds, in general, for any major problem which cannot be solved by available doctrinal methods.

For the purpose of this research the following assumptions were made:

- 1) There is no damage other than fallout. Thus the decontamination problem alone is to be studied and other aspects like debris removal and rescue work are to be considered later.
- 2) The radiation is uniform over small areas (of city block size). (In reality, terrain roughness, densely built up areas, and micrometeorological effects tend to negate this.)
- 3) There are no complications in the target area. The situation is idealized so that stalled cars, fences, trees, refuse and so on have no effect on radiation or on operations. These complications will be left for later study.
- 4) Operators will work until they have a permissible dose, and then stop (to be replaced by other operators). Their health and life will not be exchanged for additional achievement, except in an unusual situation.

- 5) All people are safely sheltered. Moreover, all people have been adequately warned so that all are indeed in shelter when attack occurs, hence rescue work will not be essential. Also once in shelter, the populace will be content to remain there until decontamination has made emergence safe.
- 6) Rate of work, and decontamination effectiveness as reported in the literature will be used as criteria for choosing optimal methods. Manipulation of process parameters such as water pressure, nozzle size, transport speed, etc. will not constitute part of the analysis.
- 7) Target structural influences on radiation will be calculated according to the examples shown in Dr. Miller's publication "Fallout and Radiological Countermeasures".
- 8) At first no special provision will be made for high priority facilities. All parts of a populated area will be considered equally important. The problem of special facilities will be dealt with after the general problem is well understood.
- 9) All people are identically influenced by the fallout, that is, nobody has a special need over any one else's, neither is anyone more or less susceptible to radiation than the "average" person.

DECONTAMINATION METHODS

The purpose of a decontamination process is to remove, as quickly as possible, the radioactive fallout material from the surfaces on which it has settled. The removal process depends on the nature of the contaminant (whether it is wet or dry) and the nature of the surface from which it is to be removed. Dry contaminant is generated by an overland atomic explosion; wet contaminant in the form of a slurry is generated by an over-water (or under-water) burst. Therefore, for wet fallout, adhesion is a problem while for dry it is not.

Decontamination processes fall broadly into two categories:

- 1) Removal of surface
- 2) Removal of contaminant alone by
 - a) Washing
 - b) Sweeping and vacuuming.

The surface removal process is applicable to loose surfaces such as sod and gravel. This can be done mechanically with motor-scrapers, bulldozers, motorgraders and front-end loaders, or manually with shovels. The mechanized equipment is applicable on open areas such as parks and fields, and readily accessible lawns. The manual methods are necessary where mechanized equipment cannot be used such as lawns with cement walks and driveways in residential areas.

Wet methods apply to paved surfaces and roofs of buildings (and sometimes walls of buildings as well). These comprise firehosing and motorized street flushing. Water velocity rather than water volume is the important mechanism of contaminant removal. For wet contaminant it may be necessary to increase the work to include wetting and scrubbing as well as flushing.

Table 1 shows a list of decontamination methods suitable for some general broad classes of surface materials. This table is based on available information in the literature. It has been arranged to allow

TABLE 1

Decontamination Methods*

Surface	Method	Process Speed ft ² /min	Remnant %	Men Required	An	As	Duty Cycle %
Paved Street	Firehose	2500	6.2	5-6	-	-	-
		1250	4.3	5-6	-	-	-
Paved Street	Sweeper						
	1 pass	2000	24	1	-	-	-
	2 passes	1000	8	1	-	-	-
Paved Street	Motorized Flusher	10,000 5,000 2,000	5 2.5 1	6 3.5 2	-	-	-
Sod	Hand Stripping	20	10	4	-	-	-
Sod	Sod Cutter & wheel- barrows	35	2	7	-	-	-
Sod	Sod Cutter (no remov- al manu- ally)	220	2	7	-	-	-
Sod	Tractor (front end loader)	70	10	2	-	-	-
Sod	Bulldozer	90	5	1	-	-	-
Tar & Gravel Roofs	Firehose	100	11	6			

* This table provides figures for an initial estimate of effort required. For a detailed analysis the tables provided in Chapter 8, Reference 1, should be consulted.

spaces for all those parameters that one needs to know in order to plan a decontamination operation. Blank spaces indicate information that is not available. The tables are arranged to show the problem surface, the appropriate method for cleaning it, the speed at which the process is applied, the remnant left after application of the process, the men required per machine or per crew, the shielding factors relating to the process and the duty cycles of the process (effective time/operating time).

THE DOSE RATE MULTIPLIER

The cumulative radiation experienced by operating personnel during decontamination and other operations should not exceed specific limits. To easily estimate the dosage accumulated by a crew, Miller has advanced the Dose Rate Multiplier concept. This is to be defined as

$$DRM(t) = \frac{1}{I(1)} \int_{t=1 \text{ hr}}^t I(t) dt$$

Thus, to calculate the dose received by a given crew member during a specific operation, it is necessary to use the formula

$$D = I(1) [DRM(t_2) - DRM(t_1)]$$

Miller bases his $I(t)$ on the equivalent ionization rate from the decay of one atom of U239 per fission activated at zero time. The DRM achieves a steady value of 3.95 in 2.3 years. For the $t^{-1.2}$ representation*, a steady value of 5 is reached. It is shown in another section that the $t^{-1.2}$ curve is good until 5000 hours, after which it departs appreciably from the actual decay curve. Whenever calculations must account for DRM (t) it is important to use the actual decay rate rather than $t^{-1.2}$.

Table 2 shows DRM values as a function of time. Figure 2 shows this relationship graphically. Figure 3 shows a graph of $DRM^*(t)$ where

$$DRM^*(t) = 3.95 - DRM(t)$$

* $t^{-1.2}$ is used in references 2 and 3 for example, to represent normal decay of radioactivity in fallout material.

TABLE 2
Dose Rate Multiplier

<u>t(hrs)</u>	<u>DRM</u>	<u>t(hrs)</u>	<u>DRM</u>
1.0	-0-	160	3.016
1.2	0.178	180	3.058
1.4	0.320	200	3.094
1.6	0.436	250	3.163
1.8	0.533	300	3.214
2.0	0.614	400	3.286
2.5	0.776	500	3.339
3	0.899	600	3.381
4	1.082	700	3.417
5	1.219	800	3.448
6	1.328	900	3.475
7	1.419	1,000	3.499
8	1.497	1,200	3,540
9	1.565	1,400	3,574
10	1.626	1,600	3,604
12	1.729	1,800	3,630
14	1.815	2,000	3,653
16	1.889	2,500	3,703
18	1.953	3,000	3,744
20	2.009	4,000	3,805
25	2.126	5,000	3,848
30	2.221	6,000	3.876
40	2.369	7,000	3.895
50	2.484	8,000	3.908
60	2.577	9,000	3.923
70	2.653	10,000	3.929
80	2.718	12,000	3.937
90	2.773	14,000	3.940
100	2.821	16,000	3.942
120	2.901	18,000	3.944
140	2.965	20,000	3.945

DRM*(t) is directly useful in calculating the incremental dosage for personnel who enter a radioactive area at time t and remain there. This dosage added to that received during operations and shelter constitutes total lifetime dose. For the general population it is the only dosage experienced, if they remain in shelters with high protection factors until emergence.

THE RESIDUAL NUMBER

The residual number, RN, is a ratio of the actual dose received due to countermeasures, divided by the dose that would have been received without the countermeasures. In general, there are three major divisions in time depicting the activities of the decontamination personnel during the fallout period:

- 1) Shelter phase
- 2) Operation phase
- 3) Occupation phase

Miller has associated a residual number with each of these phases and labelled them RN_1 , RN_2 and RN_3 respectively. Thus, RN_1 represents the actual shelter protection factor. RN_2 represents the total effect of structural shielding, vehicle shielding, dynamic change in radiation due to operations and so on. RN_3 represents the remnant fraction of fallout material remaining after operations are completed and includes also the shielding advantages of structures, living patterns and the distribution of the remaining fallout.

If we designate

$$\begin{aligned}\Delta_1 \text{ DRM} &= \text{DRM}(t_1) \\ \Delta_2 \text{ DRM} &= \text{DRM}(t_2) - \text{DRM}(t_1) \\ \Delta_3 \text{ DRM} &= \text{DRM}(\infty) - \text{DRM}(t_2)\end{aligned}$$

where t_1 = operations start time,
 t_2 = operations completion time

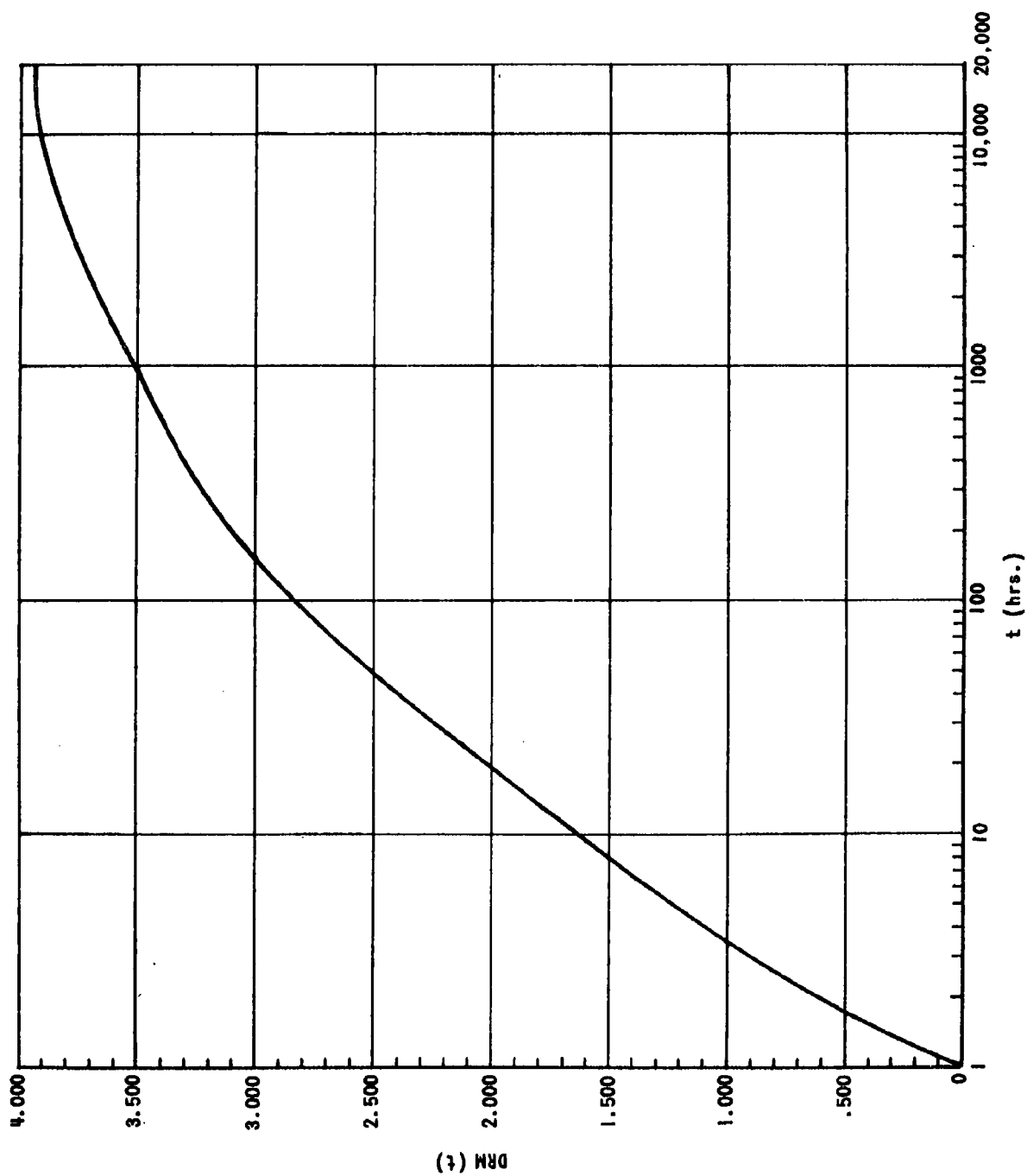


Figure 2 DOSE RATE MULTIPLIER

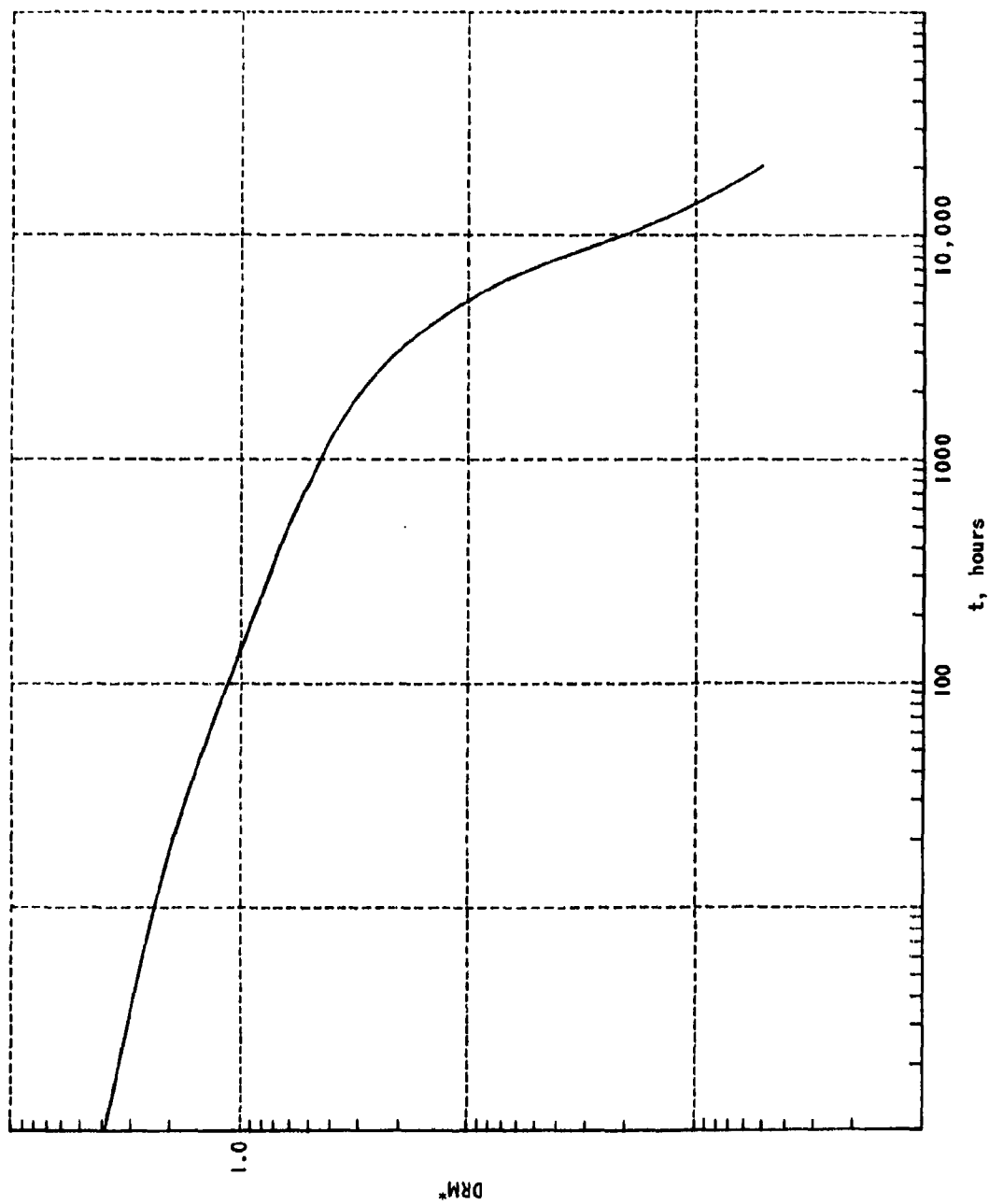


Figure 3 $DRM^* (t) = 3.950 - DRM (t)$

then the dose received by a crew member is

$$D = I(t) [RN_1(\Delta_1, DRM) + RN_2(\Delta_2, DRM) + RN_3(\Delta_3, DRM)]$$

and for non-crew personnel it is

$$D = I(t) [RN_1(\Delta_1, DRM + \Delta_2, DRM) + RN_3(\Delta_3, DRM)]$$

THE PLANNING DOSE

On the basis of information on biological effects on humans as indicated in the first section of this chapter, various criteria have been formulated for allowable dosage while operating in radioactive areas. There are various dose limits that have been used in studying decontamination operations in the past. They range from 30R to 75R per short term exposure to 150R to 1000R for a long term exposure. The limits recommended by Miller are 30R/day, 200R/week and 1000R/year. Compared to this, Lee used 30R/day, 230R/2 weeks and 1000R/year. Lee's limits are a little more conservative, and possibly somewhat more consistent than Miller's. Using the E R D concept,* the 200R/week or 230R/2 weeks are much too high. However, if the one day recovery time constant is taken into account, these limits may be satisfactory. For this report, Miller's system will be used. However, it should be emphasized that a very good scientific basis for establishing such limits is needed, and a research program to obtain this basis is well justified. These limits are an important fundamental basis of all decontamination operations, and a change in them leads to an important change in decontamination plans. For this reason, it may be useful to let the dose limits be variable, and calculate decontamination operations as a function of risk to personnel. This procedure is more difficult, of course, and for this phase of the work it is sufficient to adhere to the limits given. In future work, however, as the decontamination picture becomes very clear, it will be very worthwhile to study the tradeoffs between personnel casualties and decontamination achievements.

* NCRP 29 - (Equivalent Residual Dose)

IMPLICATIONS OF CONSTRAINTS ON RE-ENTERING FALLOUT AREAS WITHOUT DECONTAMINATION

Figure 4 shows graphically the implication of the dose limits on emergence time for the general public. This graph has been obtained by using DRM* for the 1000R/year limit, DRM (1 day) for the 30R/day limit and DRM (2 weeks) for 230 R/2 weeks. Using DRM (1 week) for 200R/1 week results in a curve that falls below the combined curve for 30R/day and 1000R/year and hence it is not shown. Also shown is a smooth curve joining the 30R/day limit and 1000R/year limit; this curve is a suggestive one with the implication that emergence time should be a smooth function of initial radiation intensity. The sharp transition between the limits for 30R/day and 1000R/year indicates that personnel who adhere to them for around 1.2K R/hour are penalized more heavily than they would be for any other value. The additional smoothing line thus may be used qualitatively, using individual judgment to decide whether 30R/day and 1000R/year are good enough limits or whether other limits should be used for intermediate values of radiation. To make such decisions it is helpful to refer to basic data such as that shown in Table 3*.

From the graph it can be seen that people who find themselves in 10,000R/hour areas will have to remain in shelter for more than seven months, those in 3000R/hour areas - 75 days, and those in 1000R/hour areas - 10 days (more if the point made previously is observed). The object of decontamination is to substantially reduce this shelter time.

OPERATIONS TIME VS. START TIME

Figure 5 is a graph from which operations time can be obtained as a function of start time, if dose limit and radiation (at one hour) are given. This graph can be used for operations planning in several different ways. If it is assumed that crews must work a minimum time to

* Or refer to NCRP 29

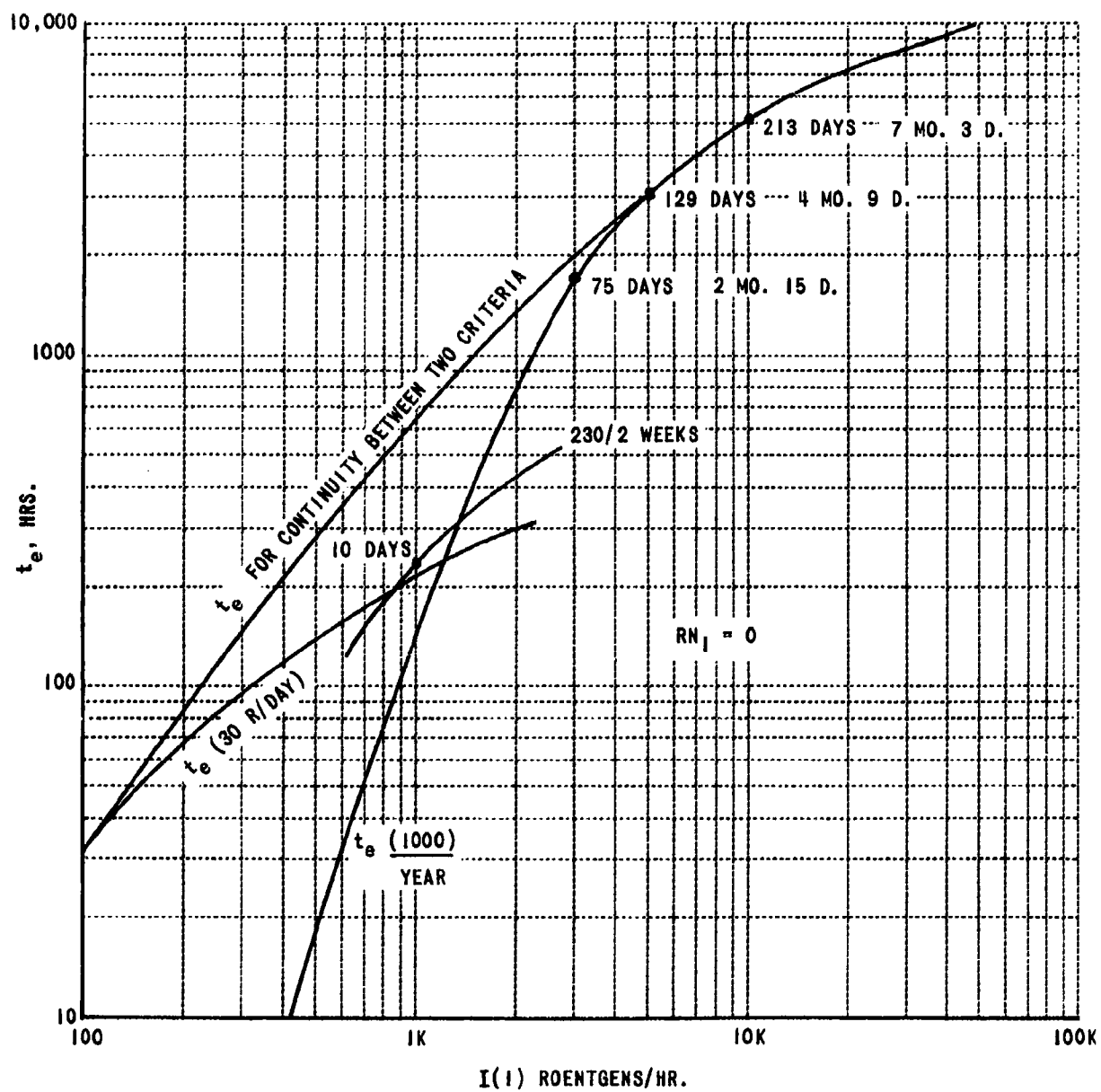


Figure 4 SHELTER STAY TIME VS. RADIATION AT 1 HOUR

TABLE 3*

Risk as a Function of Long Term Dosage

Total Dose	1 Day	3 Days	1 Week	1 Month	3 Months	Late Effects
0-75	0% sick					None
100	2% sick	0% sick				None
125	15% sick	2% sick	0% sick			None
150	25% sick	10% sick	2% sick	0% sick		None
200	50% sick	25% sick	15% sick	2% sick	0% sick	Some
300	100% sick 20% die	60% sick 5% die	40% sick	15% sick	0% sick	Some
450	50% die	100% sick 25% die	90% sick 15% die	50% sick	0-5% sick	Some
650	95%+ die	90% die	100% sick 40% die	80% sick 10% die	5-10% sick	Some

* From Radiological Recovery of Fixed Military Installations, USNRDL, August 1953

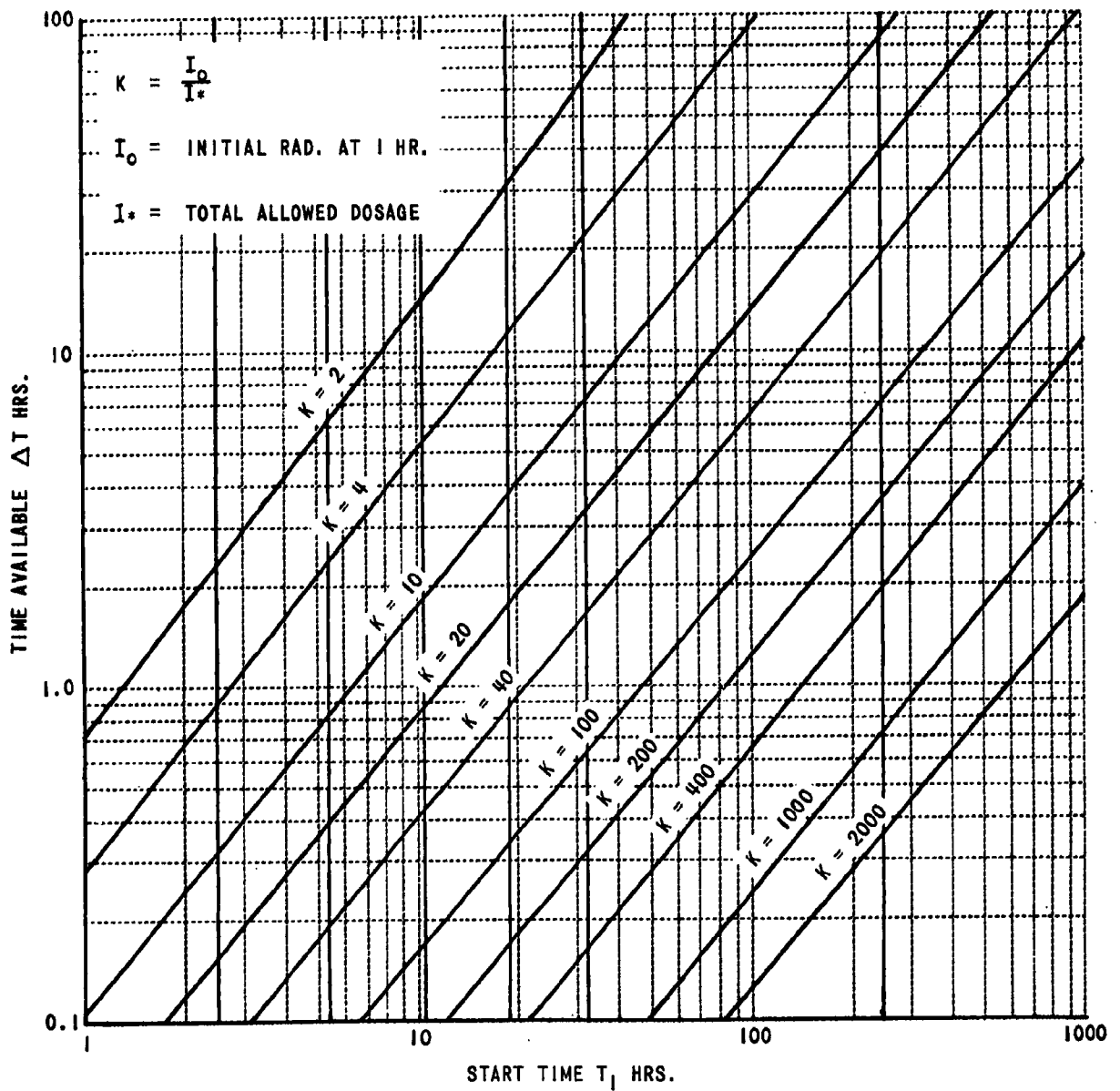


Figure 5 OPERATIONS TIME VS. START TIME

be effective, then the start time can be determined. For example, if the initial radiation (one hour) is 3000R/hour and there is a 30R limit in any given day, then $K = 100$. Now, if time required is 1 hour, then following this across to $K = 100$ and reading underneath that point yields an entry time of 47 hours after detonation. Conversely, if a need arises to go out and do something in the same area at 24 hours, then the graph tells us that 0.46 hours are available for the operation.

Another way to use this graph is to decide a given entry time and operations time, and determine from them the exposure to the operator. For example, suppose that 1 hour is required at 24 hours after attack and it is known that radiation at one hour was 3000R/hour; from the graph we read $K = 45$, approximately, and the dose sustained by the operator is $3000R/45$ which is 75R. Such an operation may be allowed to proceed if there is enough of an emergency to warrant this risk. This graph and the preceding one are basic tools for the performance of rapid estimates for decontamination, as described later.

SIMPLE METHODS FOR ESTIMATING CAPABILITIES

It is desirable to be ready to postulate a decontamination plan on short notice; should a nuclear attack occur, there is no time to perform detailed analysis. Many of the decisions will have to be made on the spur of the moment. For this purpose, it is useful to try out state of the art knowledge on a postulated situation and to see what comes of it. To do this, it is essential to make these additional assumptions:

- 1) Target shielding does not occur (studies of target effects indicate high contributions (relative to flat plane) in city complex areas for sensors placed in street centers and intersections. Hence this assumption is justifiable to an extent.)

- 2) Equipment shielding is insignificant. (RN_2 is nearly 1.0 for most equipments. Street sweepers and trucks which have RN_2 greater than 1 will not be used.)
- 3) Minimum operating time in the vicinity of a shelter is 10 minutes. Minimum operating time remote from shelter is 1 hour. This assumption provides that transport time between shelter and work need not be considered (although in some cases it may be quite important.)
- 4) "Once-through" decontamination at prevailing equipment rates will be applied, and will be sufficient. On the streets equipment rates will be limited somewhat by parked automobiles.*
- 5) People will stay in shelters for the time period that they have food available. (say two weeks). Where the stay time is in excess of this, decontamination will be applied.
- 6) In areas where decontamination cannot be sufficiently completed to allow people to get to emerge from shelter before shelter food stocks have run out, access routes will be cleared to shelters so that the shelters can be resupplied from the outside.
- 7) Mechanized operations will continue 24 hours a day until the work is done.** Manual operations requiring repeated entries by individuals and taking a long time will be done in the daytime for the endurance period of the individual (i. e. 6 hours per day on the average).

* In numerous cities many streets are crowded with parked automobiles, even overnight, because of inadequate off-street parking facilities.

** This implies that adequate lighting is required for night work.

Now the task ahead is to assess what work is to be done. It is far too difficult and complex to develop a specific plan for every possible kind of attack. To overcome this difficulty it is expedient to postulate an attack of moderate seriousness and to examine what must be done about it. A repetition of this process, over a few times, provides a set of conclusions from which it is possible to plan for a representative variety of attacks. On the other hand one may postulate maximum fallout over an entire populated area, and study the consequences. The extreme case is to postulate a multiple weapon attack on a populated area with blast, heat and radiation all acting at once. This last case may be an entirely hopeless one, however, so much so that one is inclined to give up the problem altogether. It is better to start with a much less serious problem, and then to apply the results to increasingly difficult situations.

Let us suppose that a given typical city has been exposed to the fallout from a megaton-size weapon explosion somewhere in the vicinity, but not close enough to cause serious structural damage in the city itself. How does one sketch a solution to this problem?

The first step is to have a map of the area with fallout contours plotted on it. Preferably the contours should be in terms of $I(1)$, the equivalent values at one hour. Now, using Figure 4 one can determine the natural reentry time for the general population, and if need be, plot a new set of contours depicting shelter stay times. The area contained within the boundary representing 2 weeks (or any other chosen minimum time) is the area which requires decontamination. Now, the following steps are taken:

- A. 1) Determine the total road and street surface that requires decontamination. An estimate can be made by counting roads along the center line of the city in an east west direction and also in the north south direction and multiplying the first by the north south dimension of the city and the second by the east west dimension. This yields total road mileage.

- 2) Determine house roof area that requires cleaning.
Average house dimension in a sample area, multiplied by house density will provide this. If an average house is 30 x 40 feet, and the average lot (including the street) is 60 x 160 ft. then house displacement is 1/8 and roof surface is 1/8 square miles/sq. mile of land = 3,000,000 sq. feet/per square mile of land.*
- 3) Determine amount of sod which must be removed.
 - a) on small lots
 - b) in large areas

The sod removal on small lots will have to be done either manually or with small machines. That on the large open area (parks and so on) can be done with large land-moving equipment.

B. Now, from Figure 5 determine start time, for each area, assuming that a minimum of one hour per man is required for mechanized methods and 6 hours per man - day, minimum, for manual methods.**

C. From an inventory list of public works equipment, determine how much of it is suitable for decontamination, determine respective work rates and assign the machines to appropriate activities. For example all street flushers are to decontaminate streets, all fire-hoses are to be used on rooftops, and so on. Human resources should not be forgotten - those able-bodied individuals who are doing nothing else can be assigned to sod removal crews.

* Exclusive of parks and open land.

** Firehosing will be considered a mechanized method.

From the work rates obtained in C and area estimates obtained in A the total reclamation time is available. Bearing in mind the entry constraints obtained in B a schedule of operations can be worked out for the whole area. The next section demonstrates an application of this procedure in a civil defense exercise in Erie County. Appendix I is a reproduction of the entire report submitted to Erie County Civil Defense Authorities on this exercise.

DECONTAMINATION HIGHLIGHTS OF AN EXERCISE IN ERIE COUNTY

A situation map indicated that a 1-MT bomb had gone off northwest of Buffalo with fallout damage only, to the city proper. According to the map, about 20 square miles of populated area were initially subjected to 10,000 R/hr radiation, 50 square miles more to at least 3,000 R/hr radiation and another 70 square miles to 1,500 R/hr or more.* Using a set of curves showing what stay times were required to comply to the 30 R/day, 230 R/2 weeks and 1,000 R/year dose limits (as used by H. Lee), it was estimated that the people in the 10,000 R zone would have to stay in shelter in excess of 7 months, those in the 3000 R zone for 75 days, and only those in the 1000 R or less zone could emerge in 10 days or less. Shelters with very high protection factors are assumed, so that exposures in shelter will be negligible.

Assuming that people would be perfectly willing to remain in shelters for at least 2 weeks, it was decided to decontaminate areas where radiation at one hour, $I(1)$, was in excess of 1,500 R/hr. (Near this border-line shelter stay time was 17 1/2 days). Areas outside of this dividing line would not be decontaminated.

The decontamination plan was to decontaminate roads and streets first, to wash down roofs next (except for very high buildings) and then to remove lawns. The processes chosen were simple and available methods

* These values are effective for one hour after weapon detonation.

namely: motorized street-flushers on the streets, firehoses on the roofs of houses and shovel and wheelbarrow for the lawns. Bulldozers and land moving equipment could of course expedite the effort.

Examination of a map yielded the estimate that there are 20 streets per mile in either direction or 40 miles per square mile in populated areas and also 10 miles per square mile in semi-rural areas. Since about half of the heavy fallout area was in semi-rural areas, this led to the estimate that 3500 miles of street needed decontamination. A record of available equipment in the area, obtained from the local CD authorities showed that 10 street flushers were available, thus each had 350 miles of streets to clean. On the basis of a very conservative estimate that each street flusher could clean 1 mile of streets an hour* (due to abandoned cars, refilling, travelling between water source and job location and changing of crews). This meant 350 hours of work at most, or two weeks and 1 day if the trucks were to work around the clock. Also, if crews were to work a minimum of 1 hour the first day for the job to be worthwhile, first start in the 1,500 R/hr zone, then work into higher radiation areas; then start time (or entry time) for this effort would be roughly 25 hours. (Start time for 3,000 R/hr is 48 hours and for 10,000 R/hr is five days; hence, the reason for working inwards.)

Street flushing is to be followed immediately with firehosing the roofs of houses, and the driveways. Assuming that each roof takes five minutes of effort, a one mile street of 200 homes takes 1000 crew minutes or one hour for 17 crews. Thus, if each street flusher is followed by 17 hose crews, the roofs would be decontaminated very soon after the streets. Firehose crews do not have to consist of firemen and firetrucks, -- all one needs is enough hoses and sufficient know how to handle them, as well as a ladder for each crew to mount up on the roofs.

* Speed will depend, in part, upon the amount of fallout deposited.

Lawn removal, at worst, can be done with a hand shovel and wheelbarrow. If homeowners were to get together and form work crews, -- some at their shovels, others pushing wheelbarrows, then the productivity per man is 5 sq. ft. /minute or 300 sq. ft/hour.* Assuming a lot size of 10,000 square feet (usually they are smaller) this entails 33 hours of work. If the first work day were to be six hours long, this implies an entry time of five days for 1,500 R/hour, 10 days for 3,000 R/hour and 24 days for 10,000 R/hr. Thus, one week later, i. e., 12 days, 17 days and 31 days, respectively, people would be relatively free to move around in all areas. These estimates are an upper bound to the effort required, but they serve to provide the very heartening knowledge that decontamination is very feasible to those people who believe this job to be impossible. Taking into account the gains to be expected from mechanized equipment, and the advantages of self-shielding of target areas as well as that of equipment itself and optimization techniques, the time estimates can be considerably reduced.

APPRAISAL OF THE RESULT AND FURTHER ADJUSTMENT

Now that a picture is available of the minimum that can be done, one can see some obvious methods for improving things. A street flusher proceeding at 1 mile/hour is quite slow. If arrangements can be made to have the public drive their cars off the streets before taking shelter the flusher would be able to move along more rapidly. Indeed it may be more efficient to operate the flusher at speeds of 20-50 miles/hour** to remove only that amount which needs to be removed.

* It is assumed that people will be rotated from shovel to wheelbarrow. The figure used here is based on 2 shovel men and 2 wheelbarrow men working as a 4 man crew.

** Ref. 1, Ch. 8, p. 18 (in draft report) indicates 20-30 mph. This is an area which requires further experimental investigation.

Another technique is to run several flushers, one after another, rather speedily if more cleanliness is required. Lawn removal may be done by faster methods than by hand shovel. If an adequate supply of front end loaders is available, together with dump trucks, lawn removal can be speeded up. In addition, some housing developments are so arranged that, if fences are removed, large land equipment would be able to clear up all the back yards in a block in very short order. Thus, for the back yards, at least, it would be better to concentrate manual effort on fence removal, and removal of all other back yard items while the bulldozers did the rest. Finally the hand shovel could be applied to the small areas which were inaccessible to the mechanized equipment.

After consideration of operations has resulted in more or less an optimal plan, further refinement can be applied by taking into consideration the RN_2 due to structures, to the equipment, and due to the techniques. For these refinements the techniques of the following chapters will be appropriate.

V. MODELLING TECHNIQUES FOR SYSTEMS ANALYSIS

THE PURPOSE OF MODELLING

A central problem in determining schedules for optimal operations is the radiation response of the operators to the varying radiation intensities encountered during operations. Various criteria have been postulated for dose limits as a function of time, usually there are two or three values. Use of these figures leads to difficulty, however; without the application of intuitive judgement, they may be misapplied. The ERD concept described in NCRP 29 together with an ERD limit of 200 R seems to be a rather consistent concept for operational use.

With the ERD limit as a constraint, it is desired to optimize system performance. Often it is easier to model the system on an analog computer, to try out schedules and methods etc. than to study the problem analytically. The analog computer is not expensive to use, yet with it, the scientist can scan numerous possible methods of problem solution much more quickly than he can do so analytically. Towards this objective, some of the concepts applicable to decontamination operations will be given in a form suitable for modelling on analog computers.

DECONTAMINATION CRITERIA

The purpose of decontamination operations is to keep people alive, healthy, and as cheerful as possible under the circumstances. It is desirable to prevent that hopelessness and pessimism which will lead to further losses when they are not necessary. Most important, of course, is that a sufficient amount of decontamination must be accomplished to permit people to reoccupy their homes within an acceptable period of time. It must be borne in mind that an extensive shelter stay time is a source of hazard in itself inasmuch as people will run out of food, children will get

sick, psychological depression will set in and so on. Thus, it is apparent that a trade-off exists between going out and trying to improve the situation, at the risk presented by exposure, and extending the stay in shelter. This trade-off is pretty hard to define, hence rather arbitrary, but realistic criteria, are required by which to make decisions concerning what to do and when to do it. For a theoretical study, an a priori decision must be made what dosage limits can be allowed for the public, based on alternate risks. (NCRP 29 makes suitable recommendations) If the most important objective is to gain time, all resources should be applied to reduce radiation to that level where these limits are complied with. The second objective should be to accommodate all the population in a fair way. Each individual should feel that he is getting a fair and square share of the benefit. It is to be hoped that a fair and square deal does not imply extinction for everyone, for if it does, another criterion must be chosen.

The following criteria, therefore, do not apply to the major part of this problem:

- 1) Minimize cost
- 2) Minimize effort
- 3) Minimize radiation
- 4) Minimize economic losses

Instead, the objectives are: (within the constraint of allowable dosage)

- 1) Help as many people as possible.
- 2) Get them out of shelter as quickly as possible.

These two criteria must be applied in combination with one another. Moreover, they are applicable for a situation where many people would have to stay

in shelter unduly long periods of time without decontamination.

Where the situation is less serious it is suitable to relax the above criteria somewhat, and devote part of the effort toward the restoration of the local economy. The case of a very serious situation in which injury and death have occurred because of blast and heat will not be discussed at this stage.

The above criteria can be expressed as a minimization of the expression.

$$\sum_i T_s(i)$$

where $T_s(i)$ is the shelter stay time of the i^{th} person. If it is desired to talk of groups of people P_j where P_j is the population in area j , then we seek to minimize

$$\sum_j P_j T_s(j)$$

where $T_s(j)$ is the shelter stay time in area j .

This expression can be generalized by the form

$$\sum_j P_j^m T_s(j)^n$$

where m and n are manipulable to provide a bias for extending preferred treatment of some kind to large populations and those who must endure long stay times. Heuristically, it would seem appropriate to set m at 1. Putting n at 2 or 3 or some larger value will tend to provide more effort for high radiation areas, and would influence more simultaneity in the emergence time for everyone. Here the trade-off is to help victims in highly radioactive areas at the expense of leaving those in less radioactive shelters for longer periods of time. For the sake of preliminary analysis it is suitable to choose m and n equal to 1 and also to assume that the

population can quite readily remain in shelter one or two weeks, depending on the situation.

This implies minimization of the expression

$$\sum P_j^m (T_s(j) - T_k)^n$$

where T_k is the time everyone is prepared to stay in shelter anyway. Here m and n are 1 as in the previous case.

After such an analysis is completed, variation of m and n may be performed to check qualitatively if better effects can be obtained thereby.

Other criteria which have been applied to special problems in this report are:

- 1) Start work as soon as it is feasible to do so in areas where stay time exceeds two weeks, and continue working until the whole area has been decontaminated, using rates of work available from the literature.
- 2) Given entry time and remnant, minimize radiation dose to crew. This condition applies when it is feasible to trade off entry time in order to reduce dosage to the crew.

OPTIMAL ORDERING OF PROCESSES

For any large area, where facilities are limited, all parts of the process will operate simultaneously, although each process will operate on different areas. It is much more efficient if the various parts of the process are applied in sequence to any given area, rather than that they are applied simultaneously. This has the important advantage that one process reduces the radiation for the next, thus making it feasible for the personnel of the

second process to remain on the job longer. In addition, this decoupling avoids interference between different operating machines, and also, the individual process speeds are not held back because of slowness on the part of any of the others. The following analysis shows how to choose process sequence.

Assume a fixed area. Let Y_1 be fraction of contaminant removed by process #1. Let Y_2 be fraction of contaminant removed by process #2. Let P_1 , P_2 be the relative penalties attributable to using process 1, 2 and 2, 1 respectively (i.e, penalty is proportional to radiation exposure in man-roentgens).

$$P_1 = I [T_1 + (1 - Y_1)T_2] \quad , \quad T_1 = \begin{array}{l} \text{Time for} \\ \text{Process 1} \end{array}$$

$$P_2 = I [T_2 + (1 - Y_2)T_1] \quad T_2 = \begin{array}{l} \text{Time for} \\ \text{Process 2} \end{array}$$

$$\frac{P_1}{P_2} = \frac{T_1 + (1 - Y_1)T_2}{T_2 + (1 - Y_2)T_1}$$

Let $a = \frac{T_2}{T_1}$, $b = \frac{Y_2}{Y_1}$

$$\frac{P_1}{P_2} = \frac{1 + a(1 - Y_1)}{a + (1 - bY_1)} = \frac{1 + a - aY_1}{1 + a - bY_1}$$

$$= 1 + \frac{(b - a)Y_1}{1 + a - Y_2}$$

Now since Y_2 ranges from 0 to 1, $1+a-Y_2$ is always positive.

Hence,

$$\begin{aligned} P_1 &< P_2 && \text{if } b < a \\ P_1 &= P_2 && \text{if } b = a \\ P_1 &> P_2 && \text{if } b > a \end{aligned}$$

The object is to minimize penalties due to process sequence. Thus, if one knows the values of a and b (these can be obtained from Table 4.) then optimal sequence can be chosen. The analysis can be extended to three or more processes.

BIOLOGICAL EFFECTS OF RADIATION

The effects of short term radiation are summarized in Table 4.*

* Effects of Nuclear Weapons, 1957

TABLE 4

Casualties as a Function of DosageDosage Roetgens

Up to 50	Minor blood changes. No other effects
100	Fatigue, vomiting, nausea in 5-10% for one day
150	Fatigue, vomiting, nausea in 25% for one day
200	Fatigue, vomiting, nausea in 50% for one day
300	Fatigue, vomiting, nausea in 100% for one day; 20% deaths in 2-6 weeks; convalescence for three months
450	Fatigue, vomiting, nausea in 100% for one day; 50% deaths in one month; convalescence for six months
650	Nearly 100% deaths, survivors convalescent for six months
1000	No survivors

This information is depicted graphically in Figure 6.

THE EQUIVALENT RESIDUAL DOSE

The relationship between human response to short term radiation and long term radiation is not entirely clear. It is known that substantial recovery occurs after an exposure. Devaney^{*} states that the irreparable effect of exposure is equivalent to one-tenth of the initial exposure and that this state of repair is reached in three months. Moreover, he states that half of the reparation process is accomplished in one month.

* Devaney, John F., Operations in Fallout, OCDM-SA-61-13, June 1961.
Also NCRP 29

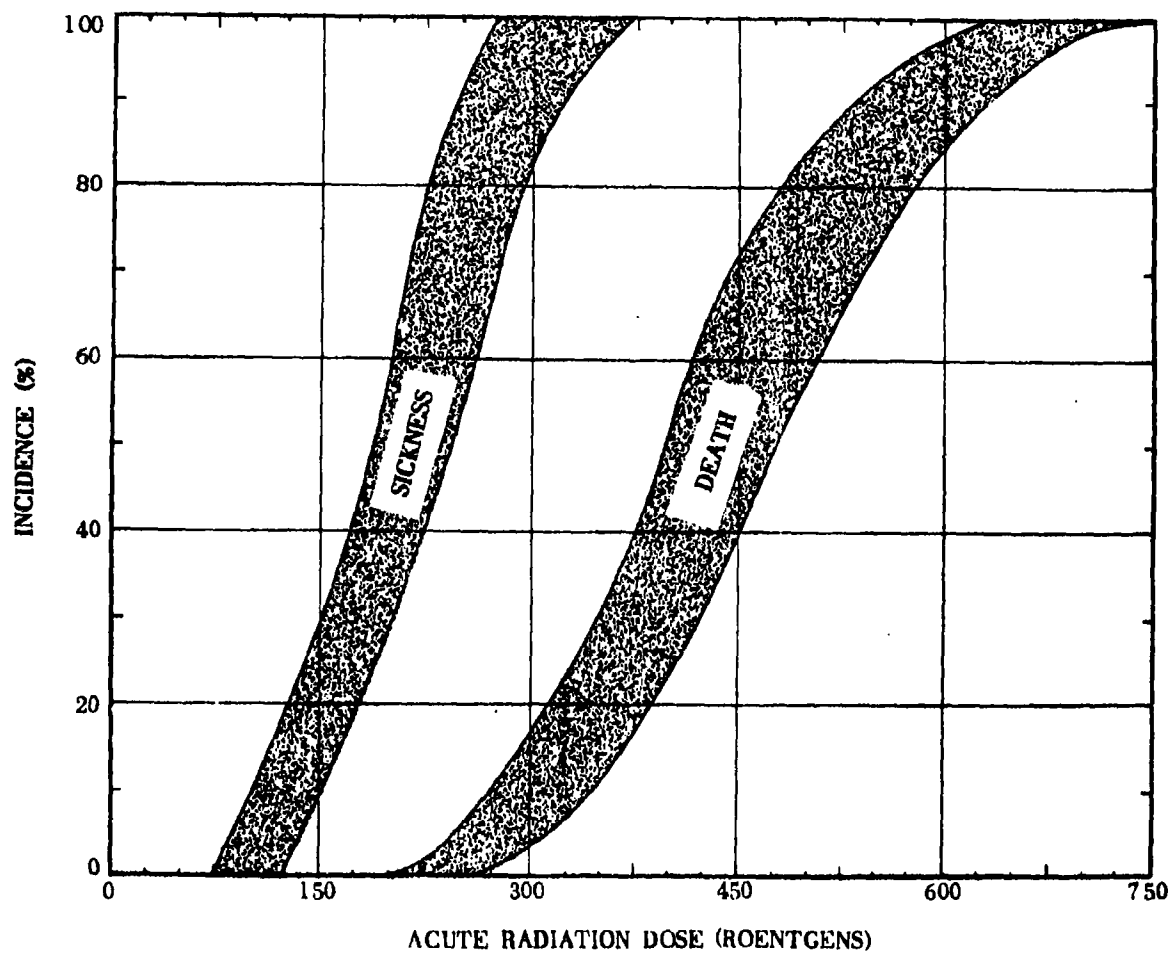


Figure 6 CASUALTIES AS A FUNCTION OF SHORT TERM DOSAGE (Ref. 3)

Considerable experimental work was done with animals, specifically mice and rats, to determine the nature of the recovery process. Much of this is reported in Claus*. This information is not very coherent; however, the following things seem to emerge:

- 1) The recoverable injury decreases approximately at a rate described by

$$f = e^{-\lambda t}$$
- 2) Recovery rate diminishes rapidly as dose increases beyond one half of LD_{50} . (LD_{50} is the dosage which leads to 50% mortality of the population.)
- 3) There is a component of rapid recovery over a very short period of time (several hours to one day).

Putting 2 and 1 together suggests a recovery rate described by

$$f = e^{-(D^* - k LD_{50})\lambda t}$$

where k is somewhat greater than 1, possibly 1.5 or 2 and D^* is the equivalent impulse dose in a mathematical sense.

Using Devaney's concept, one may state a linear equivalent recovery function to be

$$ERD(t) = \frac{D^*}{10} + \frac{9 D^*}{10} e^{-\lambda t}$$

with λ chosen such that ERD is the equivalent dosage of the remaining effect. Let this be $h(t)$, the human response to radiation. The response to time varying radiation is then

$$ERD(t) = \int_{t_0}^t I(\tau) h(t-\tau) d\tau$$

* Claus, W. D., Radiation Biology and Medicine, Ch. 12, Addison Wesley, 1958.

This is a linear function which is Laplace transformable, hence

$$ERD(s) = I(s) H(s)$$

Using the Laplace transforms of $I(t)$ and $h(t)$ separately one may obtain the transform of $ERD(s)$ and by the inverse transform obtain $ERD(t)$.

For the sake of this development, the transform of $h(t)$ is

$$H(s) = \frac{1}{10s} + \frac{9}{10(s+\alpha)}$$

where $\alpha = .000964$ to accomplish 0.45 recovery in 30 days. Here time t is measured in hours.

If we wish to take account of the 3rd item mentioned previously, this formula must take the form

$$H(s) = \frac{a}{s} + \frac{b}{s+\alpha} + \frac{c}{s+\beta}$$

where β represents the quick recovery time (24 hours) constant and α the longer (1 month plus) recovery time constant. However, since little information is as yet available, this formula will not be developed further.

THE RADIATION DECAY CURVE

The decay rate of fallout material depends on what radioactive components it is made up of, since their separate rates, which vary widely, make up the decay rate of the composition. Figure 7 shows graphically a typical decay rate for fallout resulting from an overland explosion. The solid line is actual value and the dotted line is a $t^{-1.2}$ representation.

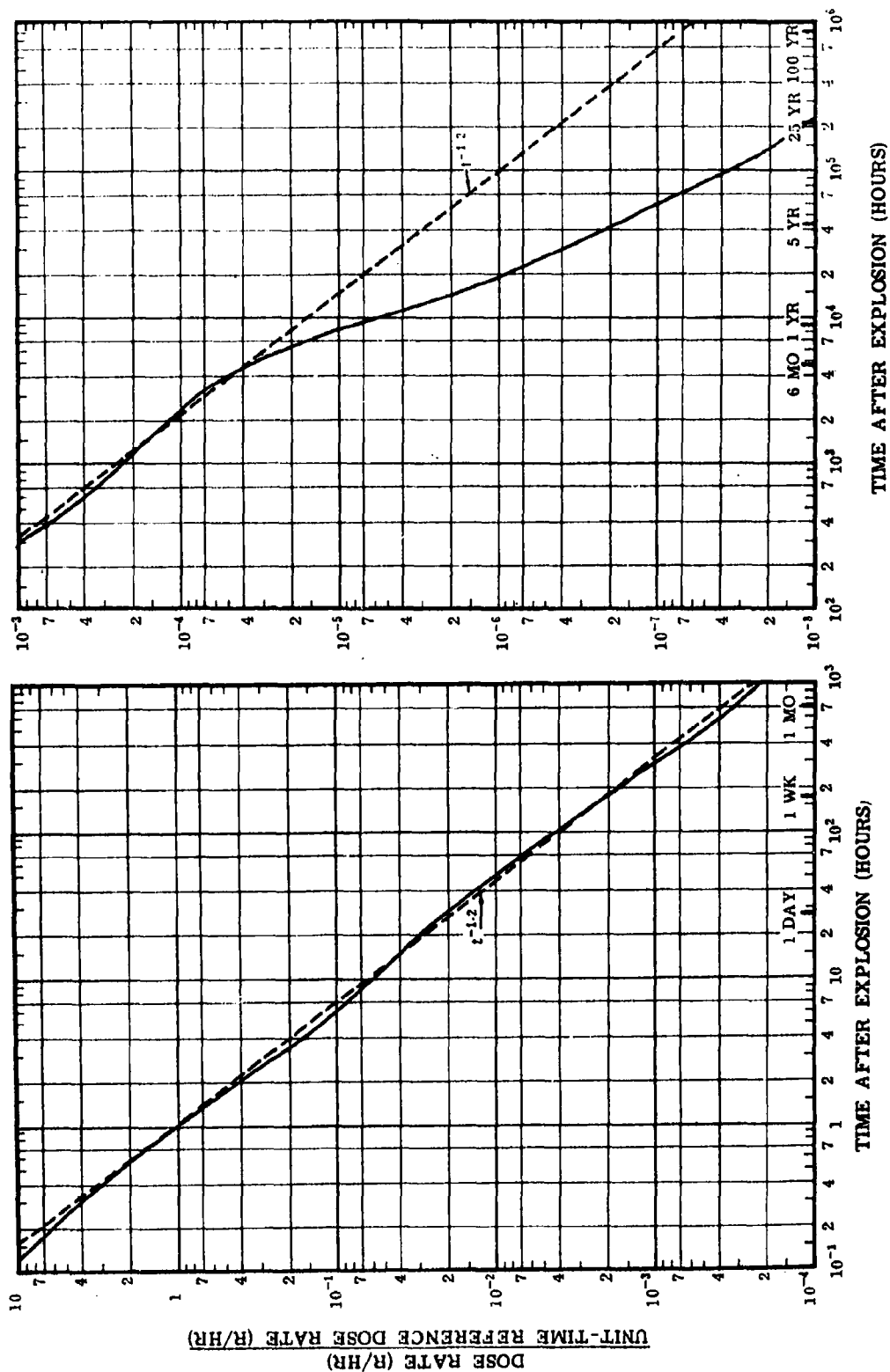


Figure 7 RADIATION DECAY CURVE (Ref. 2)

Here it is seen that $t^{-1.2}$ is quite representative all the way out to 5000 hours after the burst. Since the most important part of the reclamation operation will be performed within that period of time, the discrepancy after 5000 hours will not be important, except for the Dose Rate Multiplier and its implications as mentioned in a subsequent section.

It is convenient to have a rule of thumb method of estimating the dose rate at various given instants of time. There is an approximate relationship such that if the rate is unity at 1 hour after detonation, then it is 0.1 at 7 hours, 0.001 at 49 hours (i. e. 7×7 hours), 0.001 at 343 hours (i. e. $7 \times 7 \times 7$ hours) and so on. In other words, if time is multiplied by seven, the radiation has decayed to one-tenth of its previous value.

Radioactivity in a fallout area builds up as shown in Figure 8.* The radioactivity increases gradually at first, as the leading edge of the fallout cloud passes over, increases most rapidly while the cloud center passes by and then gradually settles down as the trailing edge passes over. Thereafter natural decay takes place.

For computational simplicity it is useful to equate the complex radiation intensity curve with another one which starts abruptly at an equivalent fallout arrival time and then decays naturally. The area under both curves are made to be the same, thus determining the equivalent arrival time. The new curve can then be applied directly to the DRM concept to find the total exposure people are subjected to if they are in a fallout area where arrival is delayed.

REPRESENTATION OF THE RADIATION DECAY CURVE

For the sake of being able to simulate the decay curve with an analog computer, and also for analytical work, it would be very useful to represent the $t^{-1.2}$ expression with its Laplace transform. However,

* This is true for a single weapon fallout situation.

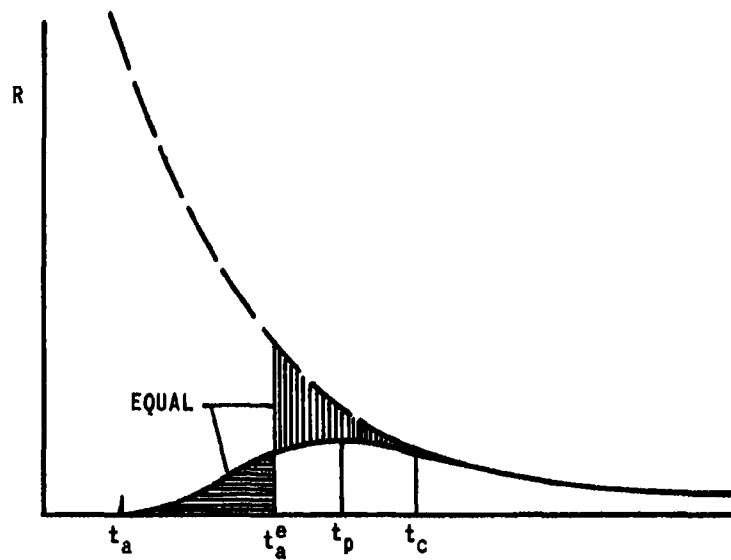


Figure 8 RADIATION BUILDUP WITH TIME (Ref. 5)

this transform is not available in readily available tables, and attempts to obtain it by performing the transformation from basic principles fail. Also, expansion into a polynomial results in a diverging series, which is also not useful. For analog computer representation, it may be adequate to represent this expression with a series of straight line segments; an expression corresponding to this may be of use analytically also, although it is tedious to handle. A possibility is to represent the decay curve with orthonormal functions, the theory of which is discussed in the next section.

POSSIBLE REPRESENTATION OF THE DECAY CURVE WITH ORTHONORMAL FUNCTIONS

A set of functions, $\{\phi_1(t), \phi_2(t) \dots \phi_n(t) \dots\}$, is orthonormal over the interval (a, b) if

$$\int_a^b \phi_m(t) \phi_n(t) dt = 1 \quad m = n$$

$$= 0 \quad m \neq n$$

If the set is also complete, any real and continuous function $f(t)$ can be represented in the interval (a, b) by

$$f(t) = \sum_{n=1}^{\infty} c_n \phi_n(t)$$

where

$$c_n = \int_a^b f(t) \phi_n(t) dt$$

Consider

$$E = \int_a^b [f(t) - \sum_{n=1}^N c_n \phi_n(t)]^2 dt$$

This expression is a minimum for the particular C_n used. Any other choice of coefficients leads to a larger value of ϵ .

Note: This is not to say that one can't achieve a smaller ϵ by choosing the first N functions of a different orthonormal set. No general procedure for selecting the "best" orthonormal set exists.

For a given orthonormal set,

$$\epsilon = \sum_{n=N+1}^{\infty} C_n^2$$

We are interested in $f(t) = \frac{1}{(1+t)^{1+\alpha}}$ over the interval $(0, \infty)$. Possible sets of functions orthonormal over $(0, \infty)$ are the Laguerre functions and also the sets

$$\phi_1(t) = \sqrt{2\rho} e^{-\rho t}$$

$$\phi_2(t) = 2\sqrt{\rho} (2e^{-\rho t} - 3e^{-2\rho t})$$

$$\phi_3(t) = \sqrt{6\rho} (3e^{-\rho t} - 12e^{-2\rho t} + 10e^{-3\rho t})$$

etc.

Each choice of the parameter ρ gives a different orthonormal set. Select the set $\phi_1(t) = \sqrt{2\rho} e^{-\rho t}$ etc. (The Laguerre functions are more complicated than these).

Evaluating the C_n entails integrals of the following form

$$S(\alpha+1, mp) = \int_0^{\infty} \frac{1}{(t+1)^{\alpha+1}} e^{-mpt} dt$$

$S(x, y)$ is Schlömilch's function*, which can be expressed in terms of Whittaker's function* W

$$S(x, y) = y^{\frac{1}{2}x-1} e^{\frac{1}{2}x} W_{-\frac{1}{2}x, \frac{1}{2}-\frac{1}{2}x}(y)$$

Thus,

$$\int_0^{\infty} \frac{1}{(t+1)^{\alpha+1}} e^{-mpt} dt = (mp)^{\frac{\alpha-1}{2}} e^{\frac{mp}{2}} W_{-\frac{\alpha+1}{2}, -\frac{\alpha}{2}}(mp)$$

This has also led us to the Laplace transform of $\frac{1}{(t+1)^{\alpha+1}}$, which is obtained by setting $m = 1$ in the above.

$$\int_0^{\infty} \frac{1}{(t+1)^{\alpha+1}} e^{-pt} dt = p^{\frac{\alpha-1}{2}} e^{\frac{p}{2}} W_{-\frac{\alpha+1}{2}, -\frac{\alpha}{2}}(p)$$

* Whittaker and Watson, "Modern Analysis" p. 352

Whether we are seeking the Laplace transform directly or via an approximation using orthonormal functions, we will have to work with Whittaker's function.

The Laplace transformation available by the above method is in fractional powers of ρ and therefore not suitable for analog use. The orthonormal functions, however, promise to be much more useful.

The approach now is to evaluate Whittaker's function (which has not been done) or to start again with the original orthonormal functions and evaluate them numerically. Since Whittaker's function may have to be evaluated numerically anyway, numerical evaluation of the orthonormal set may be the most reasonable procedure.

VI. NUMERICAL METHODS FOR ANALYSIS

A METHOD* FOR CALCULATING THE GAMMA-RAY DOSE RATE AT ANY KNOWN DISTANCE FROM A RADIOACTIVE POINT SOURCE

A sample of radioactive material is said to have an activity of 1 curie when it disintegrates at a rate of 3.7×10^{10} disintegrations/second.

Let a radioactive point source located at the point S have a strength of C curies, so that it decays at a rate of $3.7 \times 10^{10} \times C$ disintegrations/second. Assume that each act of disintegration results in the production of one gamma-ray photon of energy E Mev. Assume further that the radiation of these photons from the point source is emitted uniformly in all directions so that at a distance d cm from the point S, the photons will be uniformly distributed over a sphere of area $4\pi d^2$ cm². Neglecting the absorption of photons in travelling the distance d from the point S to the surface of the sphere, the flux \mathcal{U} at d is given by

$$\mathcal{U} = \frac{3.7 \times 10^{10} C}{4\pi d^2} \quad \text{photons/cm}^2/\text{sec} \quad (1)$$

Since each photon has an energy of E Mev, the gamma-ray flux of energy at the distance d from the point S is $\mathcal{U} \times E$ Mev/cm² sec. Define μ_e cm⁻¹ as the energy-absorption coefficient of air for the specified gamma radiation of energy E. The parameter μ_e has the property that the rate of energy absorption per cm³ at the distance d from the point S is given by

$$\mathcal{U} E \mu_e \quad \text{Mev/cm}^3/\text{sec}. \quad (2)$$

* Principles of Nuclear Reactor Engineering - Samuel Glasstone pp. 539-546

Equation (2) is referred to as the dosage rate (D_R) at a distance d cm from a C curie point source. Since the absorption of 6.77×10^4 Mev of energy per cm^3 in air is equivalent to one roentgen of gamma radiation, equation (2) is usually given as

$$D_R = \frac{U E \mu_e}{6.77 \times 10^4} \quad \text{roentgens/sec} \quad (3)$$

If an absorbing material (such as air) with an absorption coefficient μ cm^{-1} is placed between the source and the point at which the dosage rate is being calculated then equation (3) becomes

$$D_R = \frac{U E \mu_e e^{-\mu d}}{6.77 \times 10^4} \quad \text{roentgens/sec} \quad (4)$$

The energy-absorption coefficient (μ_e) of air varies with the assumed energy E per photon. However, for the range of photon energies from .07 Mev to 2 Mev, μ_e for air varies only between $3 \times 10^{-5} \text{ cm}^{-1}$ to $3.7 \times 10^{-5} \text{ cm}^{-1}$. As an approximation, μ_e is assumed to have a constant value of $3.35 \times 10^{-5} \text{ cm}^{-1}$.

It should be emphasized that D_R in equation (4) is independent of the medium exposed to the radiation and depends only on the rate of energy absorption/unit volume in air.

Using the results of equation (4) along with the assumption of an exponential decay for the radioactive point source, it follows that the dosage rate at a distance d and at an arbitrary time t is given by

$$D_R(d, t) = \frac{(3.7 \times 10^{10}) C_0 E \mu_e e^{-(\mu d + \lambda t)}}{6.77 \times 10^4 \times 4\pi d^2} \quad \text{roentgens/sec} \quad (5)$$

where

C_0 = the strength of the point source in curries
at time $t = 0$

$$\lambda = \frac{.693}{t_{1/2}}$$

$t_{1/2}$ = half life of the radioactive point source

It is understood that the point P is a unit volume and that $I_0 \Delta x \Delta y$
is defined as $\frac{2.4 E d^2 (3600)}{6.77 \times 10^4}$ roentgens/hr.

The mixture of radioisotope constituting the fission products in a contaminated area is so complex that the total rate of disintegration does not follow the usual exponential decay law applicable to a single species. Field tests have shown that if R_t is the over-all rate of gamma-ray emission at time t , and at a particular location in a contaminated area, then the rate

$R_{t+\Delta t}$ at time $t + \Delta t$ is given by $R_{t+\Delta t} = R_t \Delta t^{-1/2}$

If one makes the reasonable assumption that the dosage rate D_1 at time t is independent of position in a small area A_s within a larger contaminated area A_L , it is possible to replace the area A_L with a grid of radioactive point sources such that

- 1) The dosage rate at a distance d from each point source at one hour after detonation is given by equation (4)
- 2) The total dosage rate at any point P in the area A_s due to all contributing point sources in A_L at time t (point sources outside a circle of radius r_0 centered at P are considered to provide negligible contribution) is given by

$$D, t^{-1/2}$$

The latter assumptions form the basis of a simulation model for area decontamination studies.

AN INVESTIGATION OF THE POINT SOURCE APPROACH IN DESCRIBING A UNIFORMLY CONTAMINATED IDEAL PLANE

An ideal plane is uniformly contaminated with radioactive fallout material. Subdivide the plane into equal $\Delta x \Delta y$ elements of area ΔA . Consider an $M \times M$ matrix of areas ΔA (M assumed odd) and let ΔA_0 represent the central element of area in the matrix. Let the point P be located h units above the center of ΔA_0 and define ΔA_{ij} as the element of area ΔA in the i^{th} row and j^{th} column of the matrix.

If $\Delta x \cdot \Delta y$ is a small element of area within ΔA_{ij} , then the dose rate $DR(x, y, t)$ contribution to the point P at time t from $\Delta x \Delta y$ is given by

$$DR(x, y, t) = \frac{I_0(t) e^{-\mu \sqrt{x^2 + y^2 + h^2}}}{x^2 + y^2 + h^2} \Delta x \Delta y \quad (6)$$

where

$I_0(t) =$ intensity/hour/unit area in roentgens/hour/
unit area within the plane at time t hours

$\mu =$ linear absorption coefficient of air

Integrating over the area ΔA_{ij} , the dose rate contribution $DR(i, j, t)$ at the point P due to ΔA_{ij} is

$$D_R(i, j, t) = \iint_{\Delta A_{ij}} \frac{I_0(t) e^{-\mu \sqrt{x^2 + y^2 + h^2}}}{x^2 + y^2 + h^2} dx dy \quad (7)$$

If Q_{ij} is a point source located at the center of ΔA_{ij} and of magnitude $DR(i, j, t) \cdot d_{ij}^2$ then it follows that the total dose rate contribution $DR(t)$ to the point P at time t is given by

$$D_R(t) = \sum_{j=1}^M \sum_{i=1}^M D_R(i, j, t) = \sum_{j=1}^M \sum_{i=1}^M \frac{Q_{ij}}{d_{ij}^2} \quad (8)$$

where d_{ij} is the distance from the center of ΔA_{ij} to the point P .

Since Q_{ij} in Equation (8) involves a complicated integral, the question arises as to the existence of another form of Q_{ij} which will satisfy Equation (8). Obviously, if Q_{ij} is given by

$$Q_{ij} = \frac{DR}{\sum_{j=1}^M \sum_{i=1}^M \frac{1}{d_{ij}^2}} \quad (9)$$

equation (8) will be satisfied. It should be noted that Q_{ij} in equation (9) is constant and independent of i and j .

If the distribution of Q_{ij} 's from Equation (9) does not differ appreciably from those of the form $Q_{ij} = DR(i, j, t) \cdot d_{ij}^2$ then it would be a great simplification to describe the ideal plane in terms of a constant dose rate $DR(t)$ rather than an intensity/hour/unit area $I_0(t)$.

Data has been generated which shows that for $h = 3$ feet and $\Delta = 1$ foot the difference in the Q_{ij} 's is negligible -- less than 2% for all i and j 's in the $M \times M$ matrix. However, when Δ is increased to 10 feet, appreciable differences occur in the Q_{ij} 's -- some as high as 25%. Thus,

an extremely fine matrix is required in order to replace $Q_{ij} = DR(i, j, t) d_{ij}^2$ by the constant value

$$Q_{ij} = \sum_{j=1}^M \sum_{i=1}^M \frac{D_R(t)}{d_{ij}^2}$$

A MODEL FOR INVESTIGATING DECONTAMINATION PROCEDURES IN AN IDEAL PLANE

An ideal plane is contaminated with radioactive fallout material. Let $I_0(t)$ be defined as the intensity/unit area in roentgens/hour/unit area at time t hours in the plane. Consider any small element of area in the contaminated plane. The flux ψ at time t hours in roentgens/hour at point P located d units from ΔA is given by

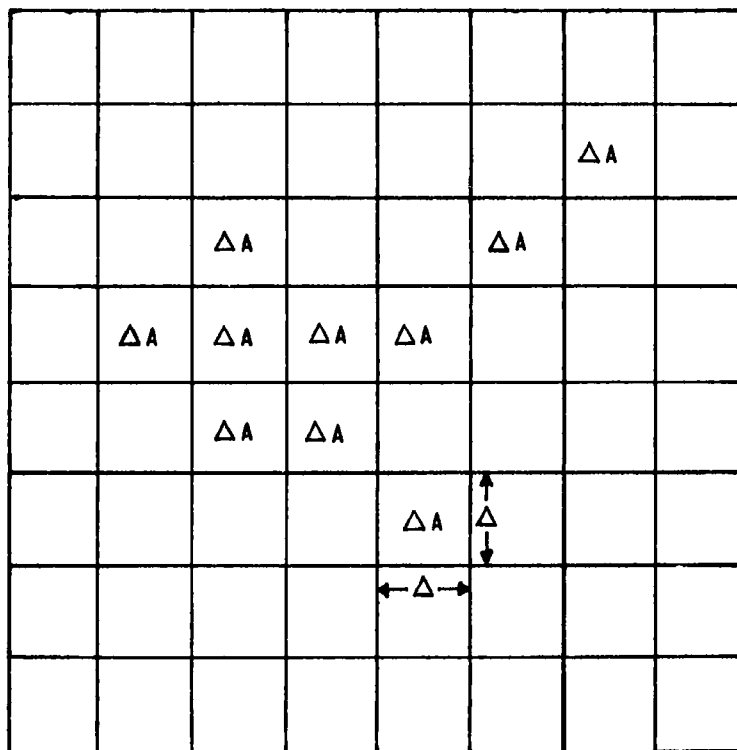
$$\psi(t, d) = \frac{I_0(t=1) t^{-1.2} e^{-\mu d} \Delta A}{d^2} \quad t \geq 1 \text{ hr}$$

where μ is the linear absorption coefficient of air and radioactive decay is assumed to follow a $t^{-1.2}$ law so that

$$I_0(t) = I_0(t=1 \text{ hr}) t^{-1.2} \quad t \geq 1 \text{ hr.}$$

The ideal plane is subdivided into equal ΔA areas ΔA as shown in Figure 9. A decontamination work crew requires Δt hours to complete one pass over any ΔA area. At the end of the time interval Δt , the particular ΔA area cleaned out is assumed to have a fraction F of the original fallout material remaining. Thus, the work crew is characterized by a work rate (/ pass / ΔA / Δt) and an efficiency F (fraction of fallout material remaining / pass) where $0 \leq F \leq 1$

Define the region to be contaminated as a finite set of ΔA areas say $\Delta A_1, \Delta A_2, \dots, \Delta A_i, \dots, \Delta A_M$. Assume that ΔA_i and ΔA_{i+1} are neighboring elements of area and of sufficiently



$I_o(t)$ = INTENSITY/UNIT AREA IN ROENTGENS/HOUR/UNIT AREA IN
THE PLANE AT TIME t HOURS

Δ = GRID SPACING

$x = ft/\Delta$

Figure 9 SUBDIVISION OF IDEAL PLANE INTO ΔA AREAS

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small size so that the time required for the work crew to move from ΔA_i to ΔA_{i+1} can be neglected.

At $t = 1$ hour, the work crew enters ΔA_1 and requires Δt hours to remove a fraction $1-F$ of the fallout material in the area. The dose received by the work crew during the Δt time interval is computed at a point h units above the center of ΔA_1 . See the last Section for a discussion of the methodology of the dose computation. The model also computes dose values h units above the center points of any finite set of ΔA areas say $\Delta A_1, \Delta A_2, \dots, \Delta A_N$. At time $t = 1 + \Delta t$ hours the work crew is assigned the area ΔA_2 where again a fraction F of fallout material is removed from the area during the Δt time interval. Dose computations are again calculated for the work crew and the areas ΔA_j $j = 1, 2, \dots, N$ during the Δt time interval from $t + \Delta t$ to $t + 2\Delta t$. The process continues until all ΔA_i $i = 1, 2, \dots, N$ have been decontaminated. The logical flow of the model is given in Figure 10.

The model has been programmed and checked out on the IBM-704 computer. Several runs have been made with the following assumptions:

- (1) The ideal plane is subdivided into 10 feet x 10 feet elements of area so that $\Delta A = 100 \text{ ft}^2$
- (2) The area requiring decontamination is assumed to be circular. Figure 11 shows the set of areas approximating this circular area.
- (3) $I_0(t = 1 \text{ hour}) = 10 \text{ roentgens/hour/unit area}$
- (4) The set of areas for which cumulative dose values are computed is the single area ΔA_1 where ΔA_1 is the center of the circular decontamination pattern.

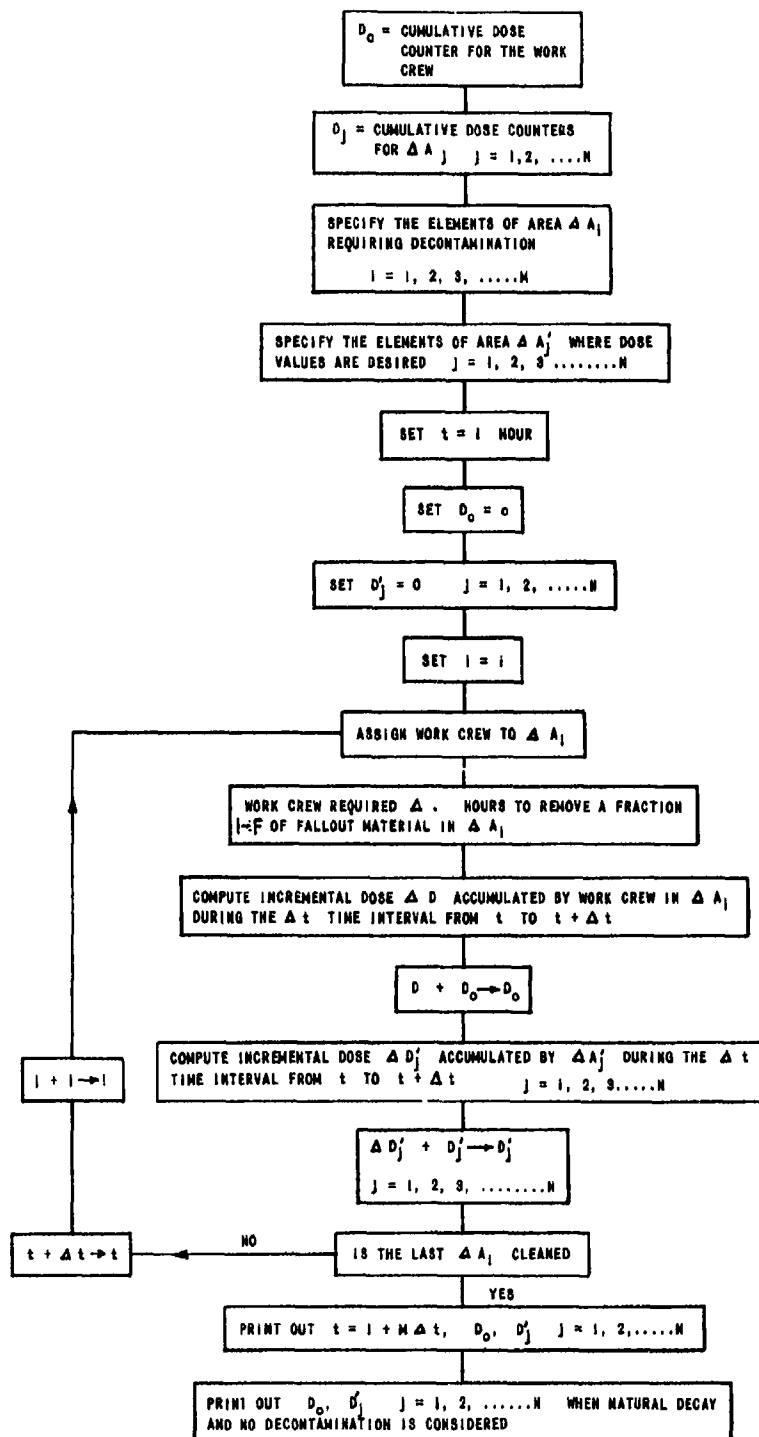


Figure 10 SIMPLIFIED LOGICAL FLOW

- (5) The linear absorption coefficient of air (μ) is assigned the value $.55 \times 10^{-4}/\text{cm}$.
- (6) Two different decontamination work crews were considered. Work crew #1 is assigned a work rate $5000 \text{ ft}^2/\text{hour}$ (equivalent to $\Delta t = .02 \text{ hour}$) and an efficiency $F = 0.1$. The work rate and efficiency F of work crew #2 are $40000 \text{ ft}^2/\text{hour}$ (equivalent to $\Delta t = .005 \text{ hour}$) and 0.9 respectively.

The results of this sample case are shown in Figure 12 where the dose received at a point P 3 feet above the center of the circular decontamination pattern is plotted vs. time. The dotted curve shows the variation of dose at P when no decontamination takes place and the only factor involved is natural radioactive decay. It is seen that the curve for the fast-inefficient work crew #2 deviates only slightly from the dotted decay curve. However, the slow-efficient crew #1 is very effective in reducing the dose level at P.

The model should be a valuable tool in investigating different combinations of decontamination procedures. For example, in the sample case considered suppose one fixed the size of the circular area to be decontaminated and equated the dose levels acquired by the two work crews. Then work crew #2 would be able to perform N passes for a single pass of crew #1. The model could be used to investigate the dose variation with time under these assumptions. It should be pointed out that the circular decontamination pattern of the sample case is not a restriction. Any geometrical pattern for the region to be decontaminated can easily be incorporated into the model.



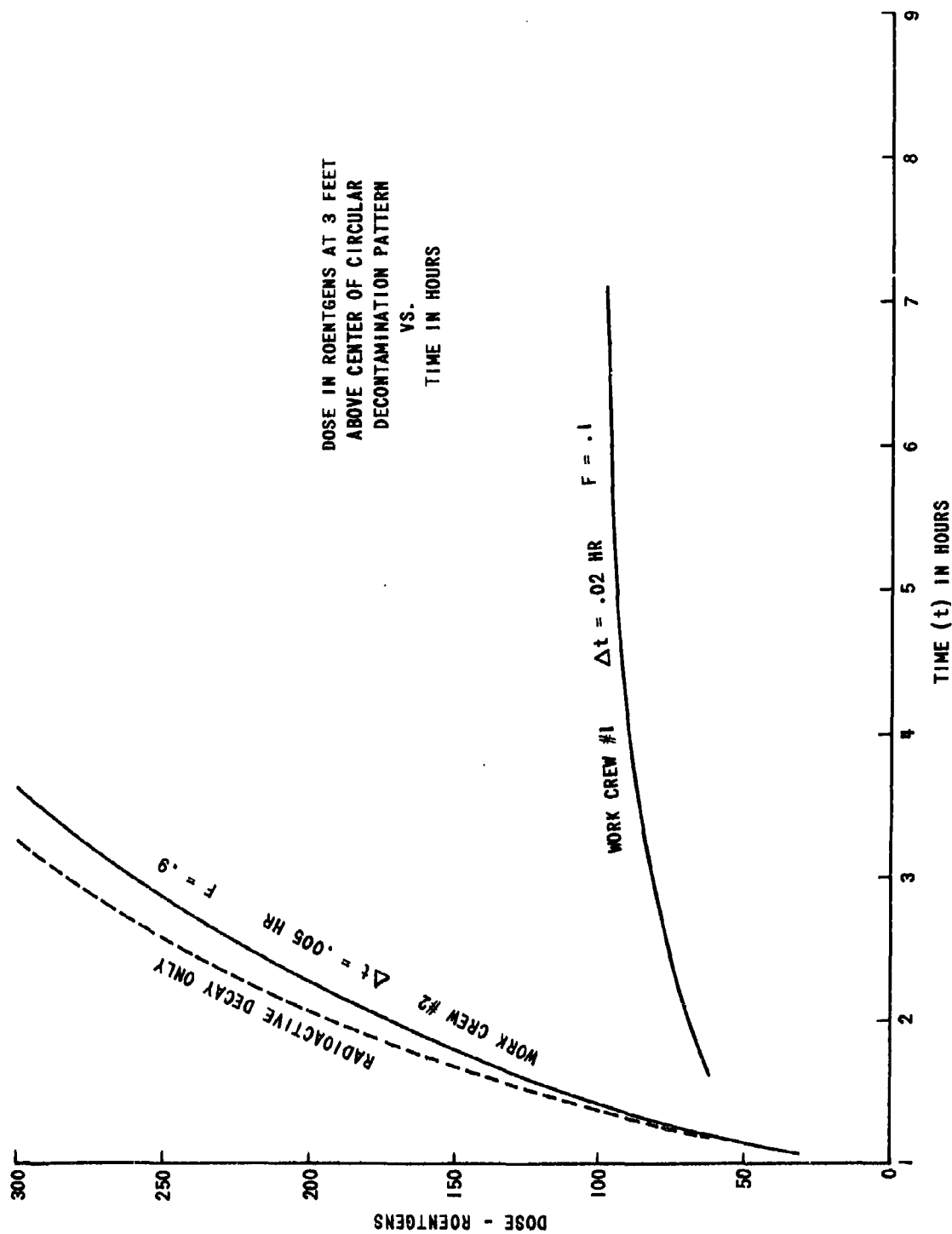


Figure 12 EFFECT OF PROCESS PARAMETER CHANGE

MATHEMATICAL DISCUSSION OF DOSE CALCULATIONS

The ideal plane is subdivided into equal $\Delta x \Delta y$ elements of area ΔA . Consider an $M \times M$ matrix of areas ΔA (M odd) specifying the central area of the matrix by ΔA_0 . Let ΔA_{ij} represent the element of area in the i^{th} row and j^{th} column of the matrix. Referring to Figure 13, let $\Delta x \Delta y$ be a small element of area within ΔA_{ij} . The dose rate contribution ($\Delta DR(x, y, t = 1 \text{ hour})$) in roentgens/hour at time $t = 1$ hour from $\Delta x \Delta y$ to a point P located h units above the center point of ΔA_0 is given by

$$\Delta DR(x, y, t = 1 \text{ hr}) = \frac{I_0(t = 1 \text{ hr}) e^{-\mu \sqrt{x^2 + y^2 + h^2}}}{x^2 + y^2 + h^2} \Delta x \Delta y \quad (10)$$

where $I_0(t = 1 \text{ hr}) =$ assumed intensity/unit area in roentgens/hour/unit area at time $t = 1$ hour

μ = linear absorption coefficient of air given as $C \times 10^{-4}/\text{cm}$ where C is dependent on the assumed energy level of the radiation.

The total dose rate $DR(i, j, t = 1 \text{ hour})$ at the point P contributed by ΔA_{ij} at time $t = 1$ hour is obtained by integrating $DR(x, y, t = 1 \text{ hour})$ over the area ΔA_{ij} . It follows that

$$DR(i, j, t = 1 \text{ hr}) = I_0(t = 1 \text{ hr}) \int \int_{\Delta A_{ij}} \frac{e^{-\mu \sqrt{x^2 + y^2 + h^2}}}{x^2 + y^2 + h^2} dx dy \quad (11)$$

At time $t > 1$ hour, it is assumed that (1) natural decay of the radioactive fallout follows a $t^{-1.2}$ law so that the intensity/unit area $I_0(t)$ is given by $I_0(t) = I_0(t = 1 \text{ hour}) t^{-1.2}$ (2) the fraction of fallout material remaining in an element of area ΔA exposed to n passes of a decontamination crew is given by $(F)^n$ where F is the fraction of fallout remaining/pass.

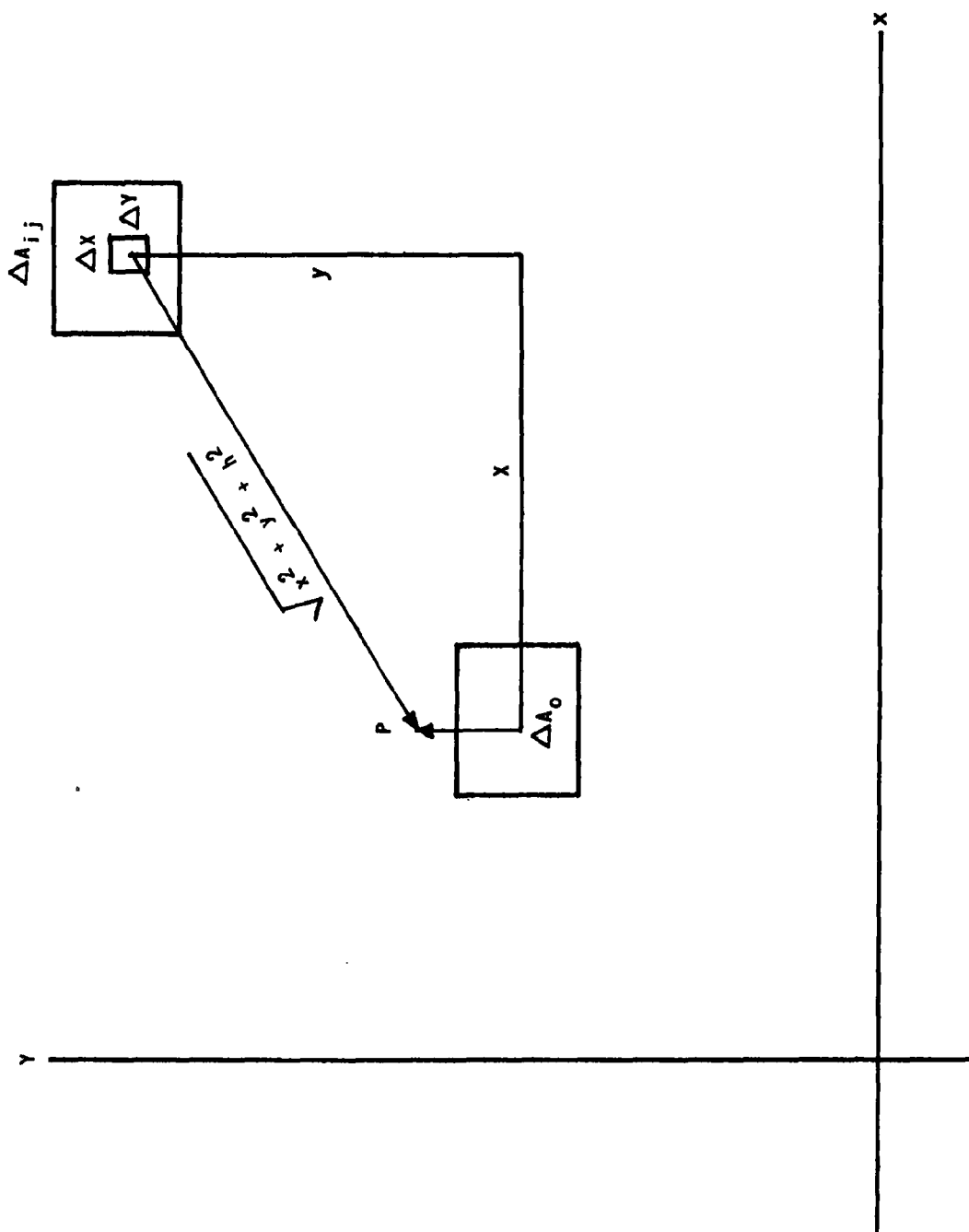


Figure 13 GEOMETRY FOR DOSE RATE CONTRIBUTION TO P

Specify an arbitrary element of area ΔA as the central area ΔA_0 of the $M \times M$ matrix. Equation (11) specifies the dose rate contributions from the ΔA_{ij} areas in the matrix but at time $t = 1$ hour. At time $t > 1$ hour the dose rate contribution to P from ΔA_{ij} can be written as

$$DR(i, j, t) = (F)_{ij}^n t^{-1.2} DR(i, j, t=1 \text{ hr}) \quad (12)$$

where F_{ij}^n is the fraction of fallout material " F^n " at time t for ΔA_{ij}

From Equation (12), the total dose $D(t, M)$ in roentgens received at the point P during the time interval from t to $t + \Delta t$ due to the M^2 areas ΔA_{ij} in the matrix is given by

$$D(t, M) = \Delta t \sum_{j=1}^M \sum_{i=1}^M DR(i, j, t)$$

Finally,

$$D(t, M) = t^{-1.2} \Delta t \sum_{j=1}^M \sum_{i=1}^M (F)_{ij}^n DR(i, j, t=1 \text{ hr}) \quad (13)$$

For specified values of $I_0(t = 1 \text{ hour})$ and μ , the model computes the $M \times M$ matrix of $DR(i, j, t = 1 \text{ hour})$ values from Equation (11). As M increases in size, the contribution of the new $DR(i, j, t = 1 \text{ hour})$ terms to the magnitude of $D(t, M)$ at point P in Equation (13) decreases. In fact, given any $\epsilon > 0$ there exists an M_0 such that for $M > M_0$,

$$D(t, M) - D(t, M_0) < \epsilon$$

For assumed values of $M = 51$ and $\mu = .55 \times 10^{-4}$ the $M \times M$ matrix was computed on the computer where it was found that approximately 88% of the total dose contribution at P is accounted for. If μ is increased to 1.1 the percentage increased from 88% to about 95%.

POINT SOURCE APPROXIMATION TO UNIFORMLY CONTAMINATED AREAS

An $L \times L$ area is assumed to be uniformly contaminated with radioactive fallout material. Define $I_0(t)$ as the intensity/unit area at time t within the area in roentgens/hour/unit area.

Referring to Figure 14 let P represent a point h units above the $L \times L$ area and offset a distance y_0 . It can be shown that at time t the dose rate $DR(t)$ at the point P is given by

$$DR(t) = \int_{-\frac{L}{2}}^{\frac{L}{2}} \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{I_0(t) e^{-\mu \sqrt{x^2 + (y-y_0)^2 + h^2}}}{x^2 + (y-y_0)^2 + h^2} dx dy \quad (14)$$

where μ is the linear absorption coefficient of air.

Instead of integrating over the $L \times L$ area to determine the dose rate $DR(t)$ at the point P , suppose one were to place a radioactive point source Q' at the center of the area.

Let $Q' = I_0'(t) \cdot L^2$ where $I_0'(t)$ is an intensity/unit area at time t within the $L \times L$ area such that

$$\frac{Q' e^{-\mu \sqrt{y_0^2 + h^2}}}{y_0^2 + h^2}$$

produces the dose rate $DR(t)$ as given by Equation 1 at the point P .

If I_0 and I_0' differ only slightly, then the point source method in determining dose rate calculations is a valid approximation to the integration method.

For assumed values of $h = 3$ feet, $I_0 = 10$ r/hr/unit area and $\mu = .55 \times 10^{-4}$ /cm, Figures 15, 16 and 17 show the variation of I_0' with $\sqrt{h^2 + y_0^2}$ for $L = 30$ feet, 70 feet and 110 feet, respectively.

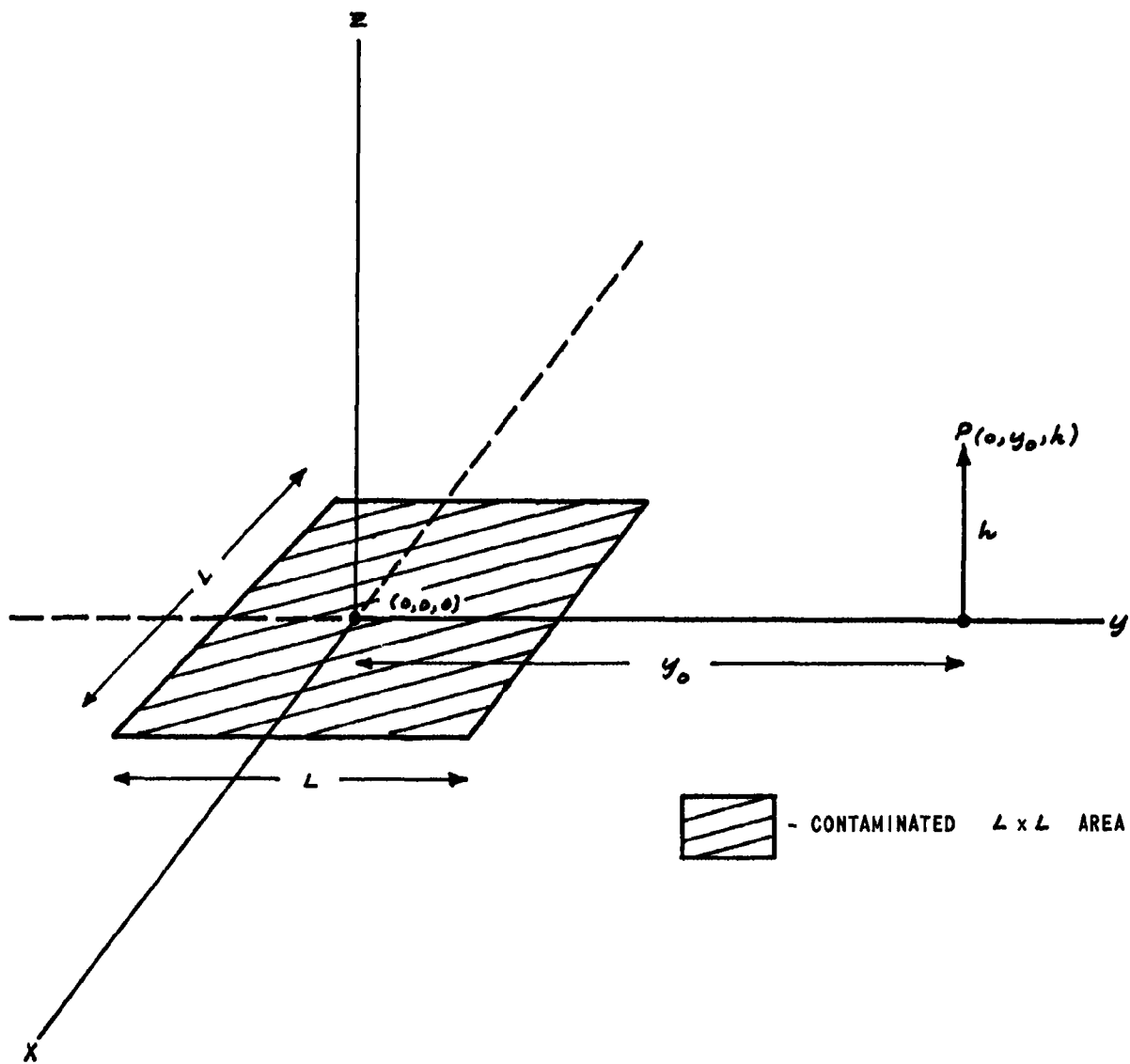


Figure 14 GEOMETRY FOR DOSE RATE COMPUTATION

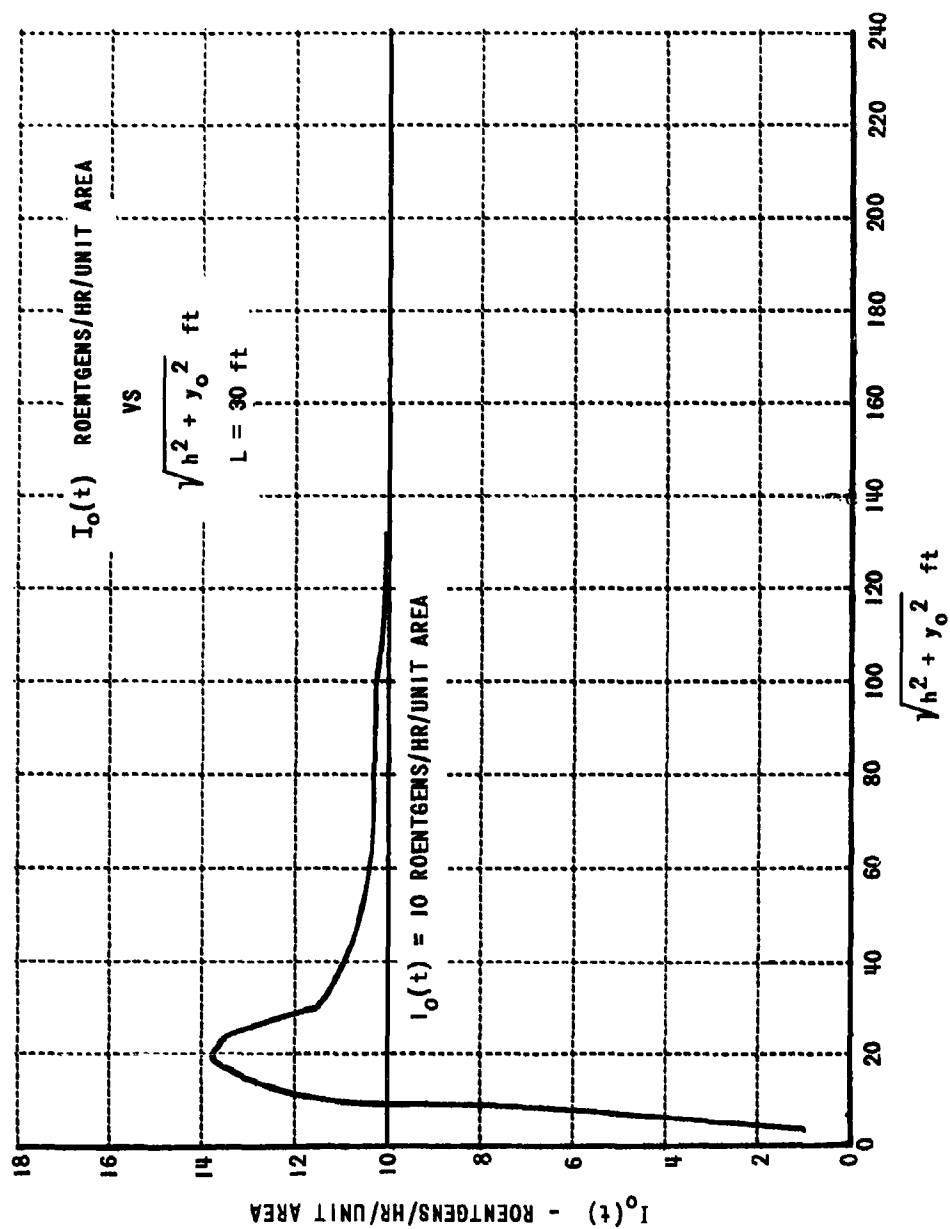


Figure 15 VARIATION OF I_0 WITH $\sqrt{h^2 + y_0^2}$ FOR $L = 30$ feet

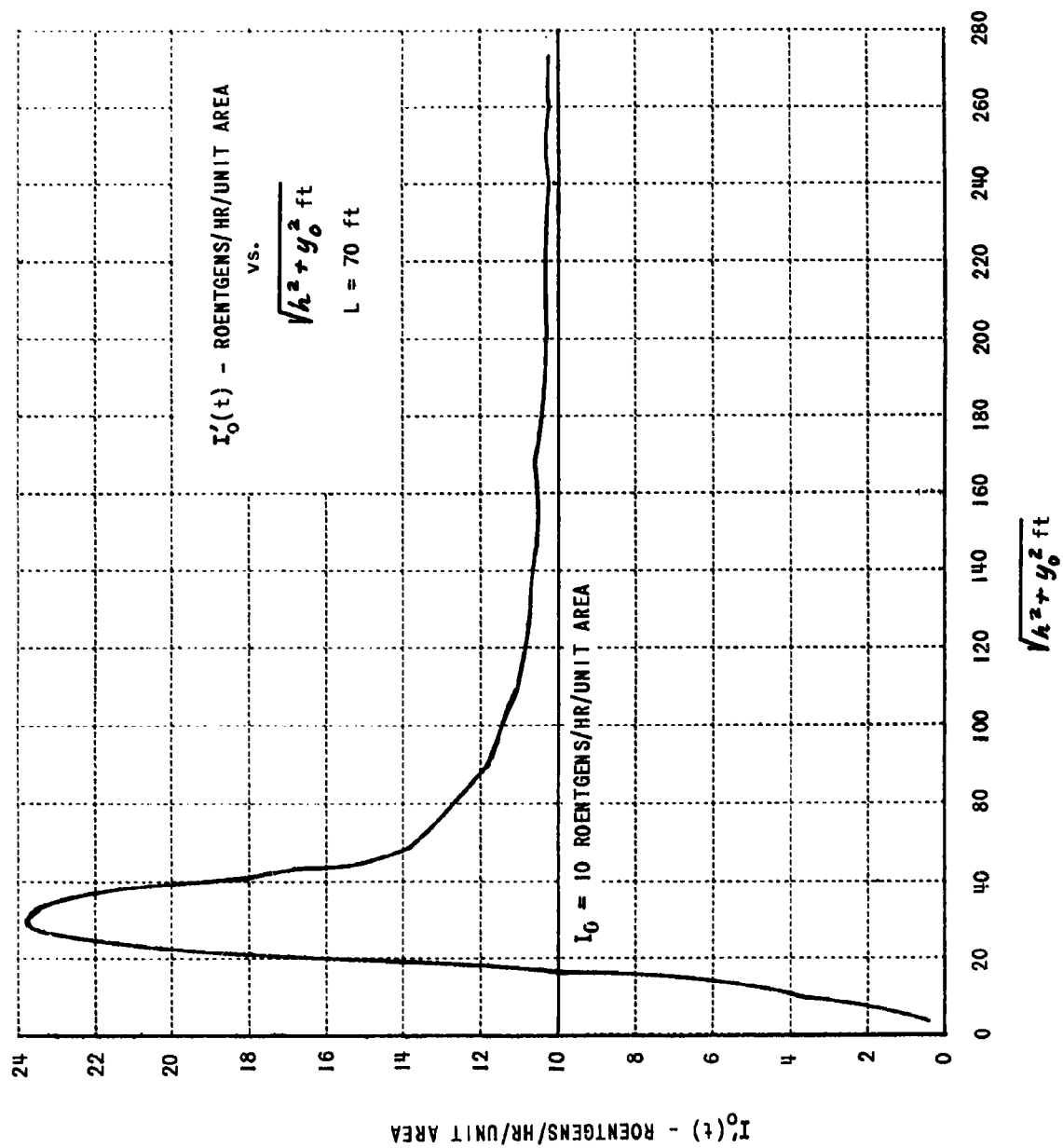


Figure 16 VARIATION OF I'_0 WITH $\sqrt{h^2 + y_0^2}$ FOR $L = 70$ FEET

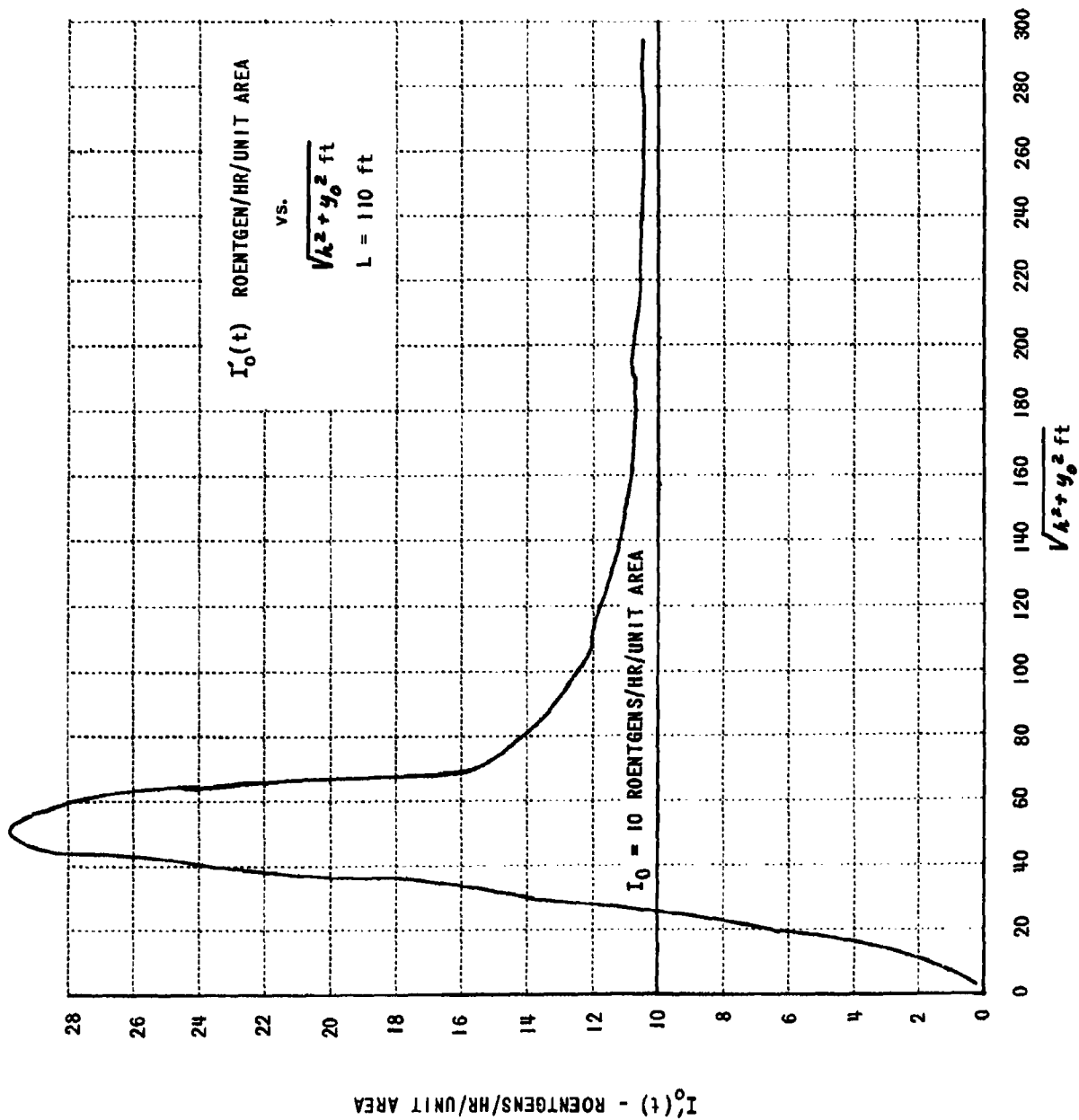


Figure 17 VARIATION OF I_0' WITH $\sqrt{L^2 + y_0^2}$ FOR $L = 110$ FEET

From the latter figures one can determine for each choice of L the distance $d(L)$ such that whenever $\sqrt{x_1^2 + y_0^2} > d(L)$

$$\frac{I_0' - I_0}{I_0} \times 100 < P \%$$

Figure 18 shows the relationship between L and $d(L)$ for $P = 5\%$.

It follows from the above data that the validity of the point source approximation to the integration method decreases rapidly with the size of the area. At the 5% tolerance level, $d(L)$ increased from 60 feet to 240 feet when L increased from 30 feet to 110 feet.

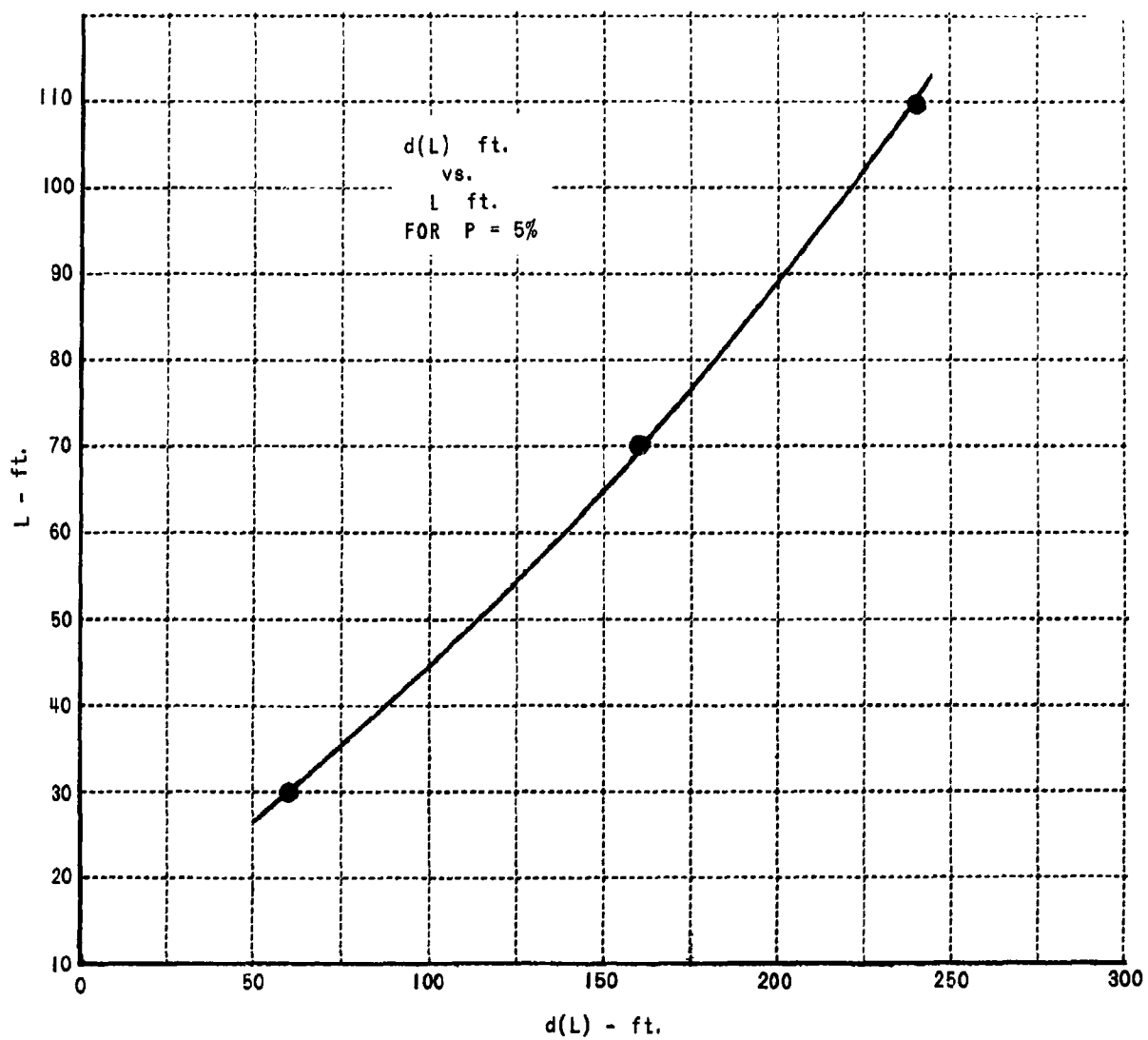


Figure 18 RELATION BETWEEN L AND $d(L)$ FOR $P=5\%$

VII. ANALYTICAL EXAMINATION OF PERSONNEL SCHEDULING

SYMBOLS USED

- t : Time-hours after the end of fallout $t \geq 1$.
- $I(t)$: Radiation decay function
 $I(1) = 1$; $I(t)$ differentiable with $I'(t) < 0$
- $R(t)$: Dose rate at time t
- $J(t)$: The amount of radioactive material present at time t
- Δt : An interval of time, immediately following t during which decontamination operations take place.
- $1 - f(\Delta t)$: Fraction of radioactive material removed in the interval t to $t + \Delta t$.
 $f(0) = 1$; $f'(\Delta t) < 0$; $f''(\Delta t) > 0$.
- D : Maximum allowable one-shot dose per worker
- t_R : Time required for worker to recover from maximum one-shot dose

GENERAL STATEMENT OF PROBLEM

Decontamination operations are to be scheduled in an area which has been subjected to radioactive fallout from a remote nuclear detonation. Find the times t_1, t_2, \dots, t_e and the associated decontamination periods $\Delta t_1, \Delta t_2, \dots, \Delta t_{e-1}$ so that certain side conditions (described in the three cases below) are satisfied. We seek and optimum schedule of the type drawn below: (Figure 19)

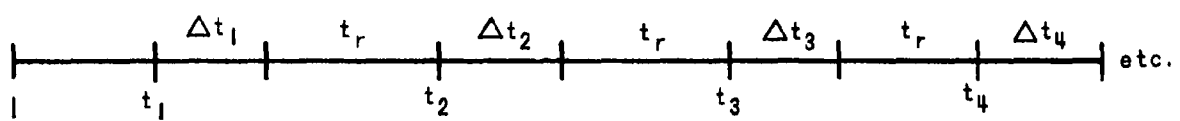


Figure 19 A SCHEDULE

Case 1

The decontamination crews, when not decontaminating, are not subject to radiation from the area being decontaminated. It is desired to reduce the dose rate from an initial level $R(0)$, to a level $R(t_e)$ by a given time, t_e . Under these conditions we wish to minimize the total dose to the crews and not exceed the maximum one-shot dose, D .

Case 2

The decontamination crews, when not decontaminating are subject to some of the radiation from the area being decontaminated. Define a number $P > 1$ which is the ratio of the off-duty to on-duty protection factors. Under these conditions we wish to minimize the total dose to the crews over the period t_i to t_e while leaving the shelter at most N times.

Case 3

Using the value P defined in Case 2, we wish to reduce the dose rate to $R(t_e)$ at time t_e while minimizing the total dose to crews while leaving the shelter at most N times.

ANALYSIS OF CASE 1

The analysis begins with a consideration of the final period of decontamination which starts at t_n and lasts for a length of time Δt_n such that $t_n + \Delta t_n = t_e$, the specified time by which the dose rate must be down to $R(t_e)$. [In this analysis $R(t)$ is simply associated with $J(t)$, the amount of radioactive material present. No attempt is made to take into account the geometry of the situation, nor is any attempt made to define further how one obtains $J(t)$ from $R(t)$ or vice versa.]

Hence $R(t_e)$ determines $J(t_e)$. Then $J(t_n)$, $R(t_n)$ and t_n must satisfy the following system of equations

$$J(t_n) f(t_e - t_n, J(t_n)) = J(t_e) \quad (1)$$

$$R(t_n) f(t_e - t_n, J(t_n)) I(1 + t_e - t_n) = R(t_e) \quad (2)$$

$$D(t_n) = R(t_n) \int_{t_n}^{t_e} f(t - t_n, J(t_n)) I(1 + t - t_n) dt \quad (3)$$

$$D(t_n) = D \quad (4)$$

where $f(t_e - t_n, J(t_n))$ has been written to emphasize that $f(\Delta t)$ does depend on the amount of radioactive material present at the beginning of the interval.

In general, iterative methods will be required for the solution of these equations. The procedure is as follows:

- a. Select a convenient trial value of t_n , say $t_{n1} < t_e$
- b. Solve equation (1) for $J(t_{n1})$. Call it J_{n1} .
This step itself may require iteration; it will depend on the form of the function $f(\Delta t)$.
- c. Substitute J_{n1} and t_{n1} into (2) for J_n and t_n respectively. Solve for $R(t_n)$
- d. Compute $D(t_n)$ from equation (3). If $D(t_n) \leq D$ select a different value of t_n , say $t_{n2} \leq t_{n1} < t_e$
- e. The iteration may be stopped when for some value of t_n , $D(t_n)$ is sufficiently close to but less than D .

After $R(t_n)$, $J(t_n)$ and t_n have been determined, we apply the same procedure to obtain $R(t_{n-1})$, $J(t_{n-1})$ and t_{n-1} , using

$$t_n - t_r \text{ in place of } t_e$$

$$J(t_n - t_r) = J(t_n) \text{ in place of } J(t_e)$$

$$R(t_n - t_r) = R(t_n) / I(1 + t_n - t_r) \text{ in place of } R(t_e)$$

In a similar manner, a sequence $t_n, t_{n-1}, t_{n-2}, \dots, t_{n-k}$ may be obtained. The process may be terminated when for some value k

$$R(t_{n-k}) \geq R(1) I(t_{n-k}) > R(t_{n-k+1})$$

Then $t_{n-k} \geq t_1 \geq t_{n-k+1}$ and t_1 is determined by

$$R(1) I(t_1) f(t_{n-k+1} - t_1, J(t_1)) = R(t_{n-k+1})$$

The curve* $R(1) I(t)$ shows the radiation rate decay curve if no decontamination takes place. The goal G_1 in Case 1 is to reduce this rate to $R(t_e)$ at a time, t_e . The process starts at G_1 and continues upward and to the left. First t_n and $R(t_n)$ are found by the iterative process described earlier. Call this point G_2 . The point G_3 provides the initial conditions for determining t_{n-1} and $R(t_{n-1})$. (Recall that in the final schedule which results from this process, no decontamination takes place during the t_r units of time from G_3 to G_2 and that the normal decay curve is applicable there. The last decontamination period starts at t_n . The curve drops more rapidly during these decontamination periods). The process continues until one of the G_k points lies above the $R(1) I(t)$ curve. The graphical example shows that three decontamination periods would be scheduled. The first is at t_1 . The

* See Figure 20

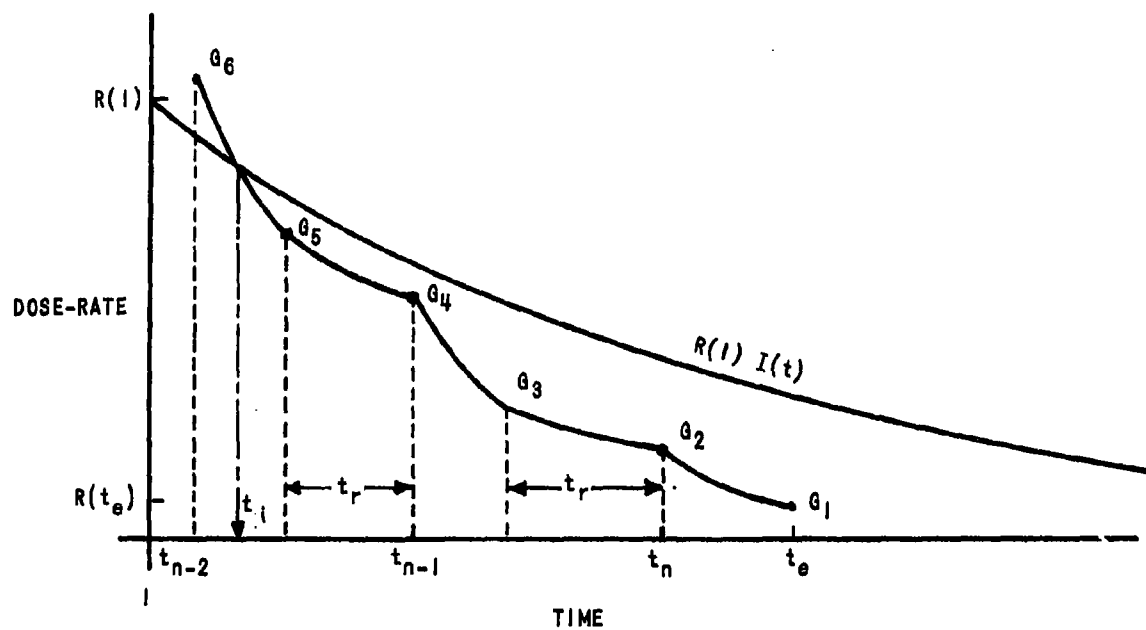


Figure 20 PROCEDURE FOR SOLUTION

second is at t_{n-1} , now to be designated t_2 . Similarly, the third period would begin at t_n and can be designated t_3 . This schedule will have the desired properties: (1) Reduce the dose rate to $R(t_e)$ at time t_e . (2) Do not exceed the maximum single-exposure dose.

ANALYSIS OF CASE 2

During the j^{th} period the total dose received is

$$R(0) \prod_{i=1}^{j-1} f(\Delta t_i, J(t_i)) \int_{t_j}^{t_j + \Delta t_j} f(t - t_j, J(t_j)) I(t) dt$$

where $R(0)$ is the initial dose rate.

Between the j^{th} and $j+1^{\text{st}}$ period (while rest and recovery is occurring) the total dose is

$$\frac{R(0)}{P} \prod_{i=1}^j f(\Delta t_i, J(t_i)) \int_{t_j + \Delta t_j}^{t_{j+1}} I(t) dt$$

The total dose is then given by

$$D_T = \frac{R(0)}{P} \left[\sum_{j=1}^n \prod_{i=1}^j f(\Delta t_i, J(t_i)) \int_{t_j + \Delta t_j}^{t_{j+1}} I(t) dt \right] + R(0) \left[\sum_{j=1}^n \prod_{i=1}^j f(\Delta t_{i-1}, J(t_{i-1})) \times \int_{t_j}^{t_j + \Delta t_j} f(t - t_j, J(t_j)) I(t) dt \right]$$

where $t_{n+1} \equiv t_e$

$$\Delta t_0 = 0$$

$$f(0, J(t_1)) \equiv 1$$

We wish to select a schedule $t_1, \Delta t_1, t_2, \Delta t_2, \dots$ which minimizes the total dose to decontamination crews over the period t_1 to t_e while leaving the shelter at most n times. To accomplish this, we proceed as follows: For every fixed t_1, t_2, \dots, t_n we minimize D_T with respect to $\Delta t_1, \Delta t_2, \dots, \Delta t_n$ and solve the resulting equations for Δt_i as functions of t_i . Then we substitute the Δt_i as functions of the t_i into D_T to obtain a function of the t_i only and minimize this function with respect to the t_i . To carry out this program, note that as a function of t_n and Δt_n ,

$$D_T = R(t) \prod_{i=1}^{n-1} f(\Delta t_i, J(t_i)) \left[\frac{1}{p} f(\Delta t_n, J(t_n)) \int_{t_n+\Delta t_n}^{t_{n+1}} I(t) dt + \int_{t_n}^{t_n+\Delta t_n} f(t-t_n, I(t)) dt \right] + \phi(t_1, t_2, \dots, t_{n-1}, \Delta t_1, \dots, \Delta t_{n-1})$$

where ϕ does not involve Δt_n or t_n .

Setting $\frac{\partial D_T}{\partial \Delta t_n} = 0$ and simplifying, we obtain

$$\frac{1}{p} \frac{df}{d\Delta t_n} \int_{t_n+\Delta t_n}^{t_e} I(t) dt + (1 - \frac{1}{p}) f(\Delta t_n, J(t_n)) I(t_n + \Delta t_n) = 0 \quad (5)$$

We also have $\frac{\partial^2 D_T}{\partial \Delta t_n^2} > 0$ if

$$\frac{1}{p} \frac{\partial^2 f}{\partial \Delta t_n^2} \int_{t_n+\Delta t_n}^{t_e} I(t) dt > \left(\frac{2}{p} - 1 \right) \frac{\partial f}{\partial \Delta t_n} I(t_n + \Delta t_n) + \left(\frac{1}{p} - 1 \right) f(\Delta t_n, J(t_n)) \frac{\partial I(t_n + \Delta t_n)}{\partial \Delta t_n} \quad (6)$$

If $I(t)$ contains Δt_n then additional terms will appear in (5) and (6). Condition (6) provides the condition on P that ensures $\Delta t_n > 0$. From (5) we obtain Δt_n as a function of t_n . Designate this function as $g(t_n)$. If t_n and $g(t_n)$ satisfy (6) and if $g(t_n) > 0$ the Δt_n minimizes D_T as a function of Δt_n . Substitute $g(t_n)$ for Δt_n in D_T and set $\frac{\partial D_T}{\partial t_n} = 0$ to obtain

$$\frac{1}{P} \frac{\partial f}{\partial t_n} \int_{t_n + g(t_n)}^{t_n} I(t) dt + \left[1 - \frac{1}{P} \left(1 + \frac{dg}{dt_n} \right) \right] f(g(t_n), J(t_n) I(t_n + g(t_n))) + \int_{t_n}^{t_n + g(t_n)} \frac{\partial f(t - t_n, J(t_n))}{\partial t_n} I(t) dt = I(t_n) \quad (7)$$

Equation (7) involves t_n as the only unknown. Solve for t_n and $\Delta t_n = g(t_n)$. Now D_T as a function of $\Delta t_{n-1}, t_{n-1}$ depends only on $\Delta t_{n-1}, t_{n-1}, \Delta t_n, t_n$, the values obtained for Δt_n and t_n may be used to repeat the above procedure to determine Δt_{n-1} and t_{n-1} . These quantities depend on $J(t_{n-1})$ and $J(t_n)$. However, the relationship

$$J(t_{n-1}) f(\Delta t_{n-1}, J(t_{n-1})) = J(t_n) \quad (8)$$

reduces the dependence to $J(t_{n-1})$ alone. Continuing this process, t_1 and Δt_1 will depend only on $J(t_1)$ which is known since $R(1)$ is known. Using the analogs of (8), $J(t_2)$, Δt_2 and t_2 are completely determined. Thus we obtain in sequence $J(t_1), J(t_2), \dots, J(t_n)$ which gives finally all the Δt 's and t 's.

Under our assumptions about $f(t, J(t))$ and $I(t)$, D_T has a unique minimum and a unique maximum. It can also be shown that, given the original assumptions, the procedure outlined is uniquely defined and satisfies $\Delta t_i \geq 0$, $t_i + \Delta t_i \leq t_{i+1}$ so that the minimum is indeed found in this way.

ANALYSIS OF CASE 3

At the end of the first period of decontamination, we have $J(t_1) = J(t_0) f(\Delta t_1, J(t_0))$; at the end of the second period we have $J(t_2) = J(t_1) f(\Delta t_2, J(t_1)) = J(t_0) f(\Delta t_1, J(t_0)) f(\Delta t_2, J(t_1))$. At the end of the j^{th} period

$$J(t_{j+1}) = J(t_0) \prod_{i=1}^j f(\Delta t_i, J(t_i))$$

Since $R(t_1)$ and $R(t_e)$ imply $J(t_1)$ and $J(t_e)$ we have

$$J(t_e)/J(t_1) = \prod_{i=1}^n f(\Delta t_i, J(t_i)) \quad (9)$$

The total dose, D_T , is the same as that of Case 2. Let λ be a Lagrangian multiplier. Then

$$\psi(D_T, \lambda) = D_T + \lambda [J(t_e)/J(t_1) - \prod_{i=1}^n f(\Delta t_i, J(t_i))]$$

Setting $\frac{\partial \psi}{\partial \Delta t_n} = 0$ and simplifying, we obtain

$$\begin{aligned} \frac{R(1)}{p} \frac{\partial f}{\partial \Delta t_n} \int_{t_n + \Delta t_n}^{t_e} I(t) dt + R(1) \left(1 - \frac{1}{p}\right) f(\Delta t_n, J(t_n)) I(t_n + \Delta t_n) \\ = \lambda \frac{\partial f}{\partial \Delta t_n} \end{aligned} \quad (10)$$

From (10) we obtain Δt_n as a function of t_n , $J(t_n)$ and λ , and as before, Δt_i and t_i as functions of λ , $J(t_i)$ and t_k , Δt_k ($k = i+1, i+2, \dots, n$). Then the equations

$$J(t_i) f(\Delta t_i, J(t_i)) = J(t_{i+1}) \quad i = 1, 2, 3, \dots, n$$

$$\prod_{i=1}^n f(\Delta t_i, J(t_i)) = J(t_e) / J(t_1)$$

together with the known values of $J(t_1)$, $J(t_{n+1}) = J(t_e)$ suffice to determine all the t 's and Δt 's

COMMENTS

1. Implicit in the total dose, D_T , formulation is the assumption that decontamination proceeds in such a way that reduction in dose rate, during each decontamination period, is proportional to the amount of material removed. This assumption is not essential. It may be eliminated by introducing the appropriate total dose calculation at each state. However, this leads to even more tedious algebra.

2. The cases examined are "fundamental" situations on which variation may be made. The fundamental features are the two sets of assumptions (Case 1 and Cases 2 and 3) and the unconstrained minimization criterion (Case 2) and the constrained minimization (Cases 1,3).

3. In Cases 2 and 3, optimization over the number, N , of stages of decontamination proceeds most easily by trying various values of N .

4. Cases 2 and 3 do not incorporate the maximum one-shot dose constraints. The following comments apply, however. If all Δt 's are such that D is exceeded, the n is too small to be feasible. If some, but not all, Δt 's are such that D is exceeded, then they should be reduced by increments sufficient so that D is not exceeded and the increments should be added to the earliest possible Δt 's in such a way that D is not exceeded for them. Exactly the same comments apply if

$$t_r > t_{j+1} - (t_j + \Delta t_j)$$

5. Case 1 applies, e.g., when it is desired to clean up useful area which poses no radiation problem to the population beyond it.

6. Case 2 applies, e.g., to the situation where there is no immediate urgency for use of the area and it is not feasible to remove the crews from the area for rest and recuperation, but that they can be sheltered near the area.

7. Comment 6 applies to Case 3 except that there is some degree of urgency as expressed by $R(t_e)$ and t_e .

8. The case where the population is also exposed to radiation from the area is treated as in Case 3. Add terms to D_T for the total dose to the population. Adopt the criterion

$$\min t_e = \sum_{i=1}^n t_i + \Delta t_n$$

subject to fixed dose for the crews. The Lagrangian term expresses the fixed dose for the crews. See Comment 2. Alternately, add terms to D_T for the population dose, make a judicious selection of $R(t_e)$ and t_e and proceed as in Case 3.

9. Assume areas A_1, A_2, \dots, A_m are to be cleaned, that they have dose rates $R^{(1)}(t), R^{(2)}(t), \dots, R^{(m)}(t)$ and that by t_e they are to be reduced to $R^{(1)}(t_e), R^{(2)}(t_e), \dots, R^{(m)}(t_e)$ while minimizing the total dose to the crews. This is essentially a combinatorial problem. Brute force with the following simplification should work. Assume that each area is to be cleaned in one stage and calculate the total dose for each ordering. Select the ordering which minimizes the total dose. It is easily shown that this ordering is still the solution if optimal schedules are adopted for each area.

VIII A COMPUTATIONAL ANALYSIS OF ENVIRONMENTAL SHIELDING

INTRODUCTION

All calculations of dose rate discussed here will be given in terms of an infinite plane dose rate, D_{∞} . The infinite plane dose rate is determined as follows: Assume that a horizontal infinite plane is uniformly covered with fallout material and has a source strength* I_0 per unit area with the entire plane immersed in air as the attenuating medium. The dose rate at a point three feet above the plane is found by finding the contribution to total dose rate from each elemental area, attenuating this by the standard medium (air) and integrating over the entire plane. Doing this yields a value for $D_{\infty} = 25309I_0$.

The infinite plane dose rate can be associated with the "unit time reference dose rate" which is ordinarily specified by the fallout contours normally plotted during civil defense operations or as commonly specified by various nuclear weapons effects handbooks. Of course, the time decay of dose rate must be considered in the usual manner for these results; also, to determine total dose, the dose rate must be integrated over the time of exposure and with normal decay. Now the fallout contours present a spatial variation in dose rate corresponding to the variations in deposits of fallout material over the ground and are not a uniformly contaminated infinite plane. Computations show, however, that the dose rate three feet above a circular disc with a radius of 600 feet differs from the infinite plane dose rate by less than one percent, so that the approximation of equating D_{∞} to the unit-time reference dose rate is useful in most practical cases.

* The source strength can be expressed in any convenient units per unit area. If the activity of fallout material is ρ per unit area, $I_0 = K\rho$, where K depends on the number of energetic particles emitted per disintegration, the energy of each particle and contains a factor which converts radiation intensity to dose rate. Since dose rates are always expressed relative to a reference dose rate in this discussion, the actual units used are irrelevant.

In this target analysis, a relative dose rate is presented for each target as a ratio or percentage of the infinite plane dose rate. In this way the results have greatest generality, and can be readily applied to an actual or postulated fallout situation and have value in planning operations since they present a convenient method of gauging the effective "shielding" which a specific target complex would provide for an exposed individual.

Certain simplifying assumptions have been made for each of the five methods of computation to be discussed. Common to all of the methods are the following:

- a) The ground is assumed to be a horizontal, infinite plane without the shielding effect which is normally encountered due to ground roughness.
- b) All areas are plane horizontal surfaces with a uniform distribution of fallout material on them.
- c) The fallout material emits gamma radiation radially outward and with equal intensity in all directions.
- d) All shielding structures in the target area have a unity buildup factor.
- e) Each element of contaminated surface area acts as a point source and the contribution from all point sources is additive.

Certain additional assumptions are peculiar to the particular method of computation and will be defined as required.

METHODS OF COMPUTATION

In general, if an area (A) has a constant source strength I_0 per unit area due to a uniform distribution of fallout material, the dose rate at a point will be given by

$$D = \int_A I_0 G(R) B(R) dA \quad (1)$$

where $G(R)$ specifies the change in radiant flux with distance R and $B(R)$ is a buildup factor in the medium through which the radiation passes. If we assume each element of area to behave as a point source and have a unity buildup factor the dose rate becomes:

$$D = \int_A I_0 \frac{e^{-\mu R}}{R^2} dA \quad (2)$$

where μ is the attenuation coefficient for gamma radiation in the medium. If the radiation passes through several (n) layers of different media, the term μR can be replaced by $\sum_{i=1}^n \mu_i t_i$ summed over all layers, where μ_i is the attenuation coefficient for the i th layer and t_i is the path length through that layer.

The problem is now one of computing the integral (2). It cannot be solved in closed form but with certain simplifying assumptions various methods for approximating the integral have been investigated.

1. Point Source at Centroid

This method is discussed in Reference 1 (Chapter 10) and assumes that the actual area covered with uniform fallout can be replaced by an equivalent point source of strength $Q = I_0 A$ located at the centroid of the contributing area. It further assumes that $e^{-\mu R}$ can be replaced by a constant attenuation factor A_j which neglects the gamma ray attenuation of air but includes that for other media. Thus, the contribution to dose rate at a point for the j th surface is

$$D_j = \frac{A_j Q_j}{d_j^2} \quad (3)$$

where d_j is the distance from the point to the centroid of the area.

2. Circular Sector with Constant Attenuation

This method is also discussed in Reference 1, Chapter 10, and contains the basic assumption that any given area can be approximated by a circular sector. Again, it is assumed that the attenuation factor is a constant, A_j . Using these assumptions, equation (2) can be integrated exactly (see the final section of this chapter) giving

$$D_j = \frac{A_j \theta_j I_0}{2} \operatorname{Log}_e \left[\frac{x_{2j}^2 + h_j^2}{x_{1j}^2 + h_j^2} \right] \quad (4)$$

for the contribution to dose rate of the j th area. In this equation θ_j is the angle subtended at the point by the projection of the j th area in the horizontal plane containing the point; h_j is the height of the area above (or below) the point of interest, and x_{1j} , x_{2j} are the minimum and maximum radii, respectively, of the j th circular sector in its horizontal projection plane.

3. Rectangular Geometry with Constant Attenuation

If we again assume that the exponential attenuation term can be replaced by a constant, A_j , integration over the actual rectangular (or any polygonal) area must be performed. Equation 2 becomes:

$$D_j = I_0 A_j \int_{y_{1j}}^{y_{2j}} \int_{x_{1j}}^{x_{2j}} \frac{dx dy}{x_j^2 + y_j^2 + h_j^2} \quad (5)$$

for the contribution to dose rate from the j th area. This integral cannot be solved in closed form and is best solved numerically by machine methods.

4. Circular Sector with Attenuation

Retaining the circular sector approximation for actual areas but considering the actual variation of the attenuation factor with distance allows us to further refine the computational model. The dose rate can be expressed (see final section) as

$$D_j = I_0 \theta_j \int_{z_{1j}}^{z_{2j}} \frac{e^{-z}}{z} dz$$

(6)

where

$$Z_{1j} = \mu \sqrt{x_{1j}^2 + h_j^2}$$

$$Z_{2j} = \mu \sqrt{x_{2j}^2 + h_j^2}$$

$$Z = \mu r$$

Values of the integral can be determined by machine using numerical integration or by hand using tabular data for the exponential integrals. As in the second method above, θ_j , x_{1j} , and x_{2j} define the circular sector which approximates the actual contaminated jth area.

5. Rectangular Areas with Attenuation

With this method the limitation imposed above by use of circular sectors to approximate rectangular areas is removed. For a rectangular area, equation (2) would be written

$$D_j = \int_a^d \int_a^b \frac{I_0 e^{-\mu \sqrt{x_j^2 + y_j^2 + h_j^2}}}{x_j^2 + y_j^2 + h_j^2} dx dy \quad (7)$$

More complex areas could be broken up into any set of rectangular areas each of which could be expressed in the form of equation (7). This integral can best be evaluated using numerical integrations by machine methods of calculation.

Methods of computations 2, 3 and 4 have been programmed for the IBM 704. Results for specific cases are shown in the next section. The first method is simple enough for hand computations to be adequate; preliminary results of calculations showed that the small differences in dose rate and the additional complexity of method 5 as compared to method 3 did not justify preparation of an additional program. A more comprehensive method of computation is discussed in Reference 4, but the extension of work to this additional degree of complexity was not felt to be warranted or required for the present study.

RESULTS AND DISCUSSION

This target analysis considered several different cases to illustrate the methods of computation and vary in complexity from simple idealized geometry to a complex city geometry which approximates an actual situation. Each of these cases will be defined and results discussed in detail in the ensuing paragraphs.

Circular discs - for this case the dose rate was computed using method 4 for finding the dose rate at a point three feet above the center of a circular disc. Air attenuation was assumed. Computations were made for discs of various radii in the range from 10 feet to 10,000 feet. Results are shown in Table 5.*

* Tables 5 to 12 are shown in Appendix II

Cylindrical farmhouse - method 4 was used to compute the dose rate at a point three feet above the center of the floor of a simple cylindrical structure which is located on a horizontal circular disc of radius 600 feet. Various structural parameters were varied; namely, the radius of the building was varied from 20 to 60 feet, holding the building height at 10 feet with walls and rooftop of wood, two inches thick; the height of the rooftop was varied from 10 feet to 35 feet, again using walls and rooftop of wood two inches thick and holding the building radius at 30 feet except for one case ($H = 27$ feet) where radii of 30 and 50 feet are computed; finally, wall and rooftop thicknesses of four and six inches of wood are used for various radii, holding heights at 10 feet. Results are shown in Table 6. Note that the contribution to dose rate from the rooftop and from the surrounding area are computed separately so that one must add the contributions from the two to determine total dose rate for each case.

Study of the data in Table 6 shows that increasing the height of the rooftop above the observer has a much greater effect than increasing building radius. Also, this case illustrates the value of even a small amount of shielding as compared to an individual exposed to the full radiation field with only air as the attenuating medium.

Residential area^{*} - an idealized target area representing a typical residential area was analyzed by both method 2 and method 4. A map of the area is shown in Figure 21. For both computations, the dose rate at a point three feet above the floor at the center of the center house is found. The results (Tables 7 and 8) show a comparison between the two methods of computation; on the one hand, the simpler method in which an exponential attenuation factor is used to multiply the integral gives a total relative dose rate of 55.8%; for the other, in which the

* This residential area is similar to the example used in Reference 1 Chapter 10, and was analyzed for use as a test case in checking out the computer programs.

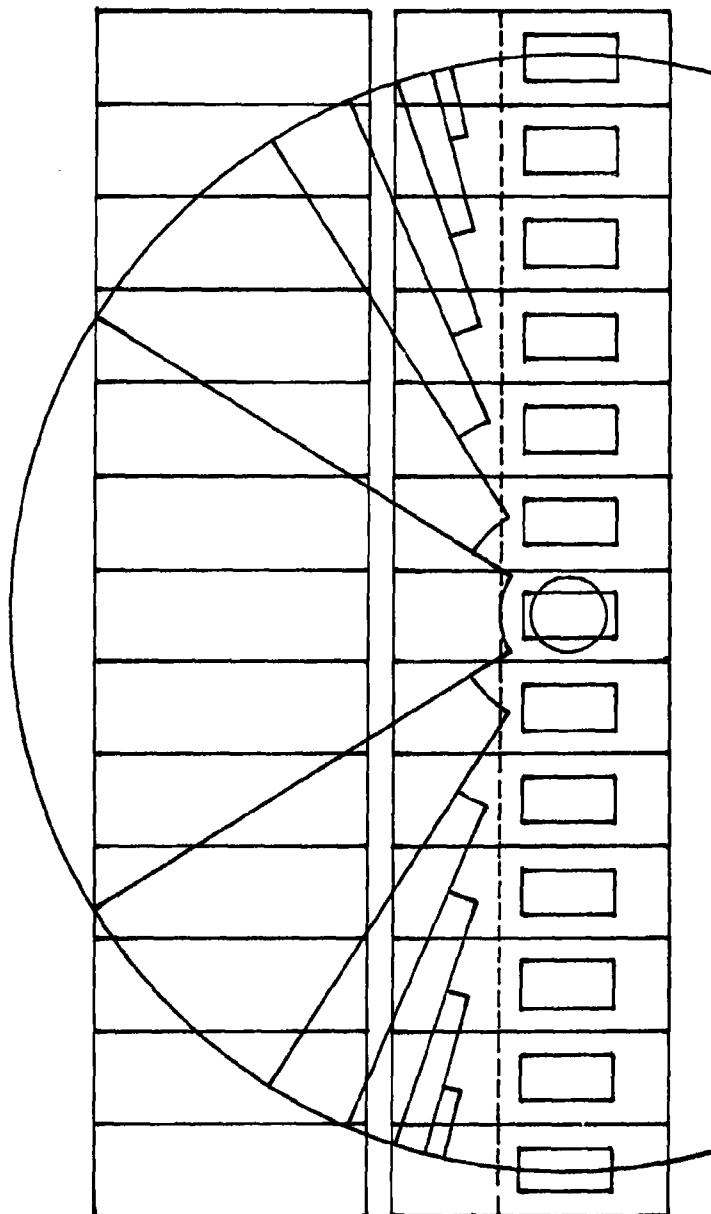


Figure 21 RESIDENTIAL AREA

exponential term enters into the integration, total relative dose rate is 50.8%. The difference between these two results is sufficiently small that use of the simpler method of computation, which is amenable to hand computations, is justifiable for use in estimating dose rates for planning purposes. Furthermore, since the simpler method will always yield higher than actual values, such estimates will be on the conservative side.

Shopping plaza - the shopping plaza case consists of a row of attached stores separated by concrete walls one foot thick. The rear wall is also one foot of concrete but the front wall was assumed to present no shielding since the display windows would have little shielding effect even if they survived the blast effects in an actual attack. Building heights were taken at 15 feet and the shielding factor for rooftops was taken as a three inch wood equivalent. Dose rate was computed at three feet above the center of the floor of the center store. A map of the shopping plaza is shown in Figure 22. The shopping plaza case was also analyzed by both methods 2 and 4. The results are shown in Tables 9 and 10. Total relative dose for the computation with "fixed attenuation" is 14.8% whereas for the computation "with attenuation" (i.e., with the exponential term retained under the integral sign) the value is 9.4%. Again the simpler method yields the more conservative estimate. It is interesting to note from these results that almost the entire dose rate is contributed by the areas immediately in front of the front window of the center store. This again illustrates the importance of shielding.

City complex - an idealized target area was analyzed representing a typical city area. Detailed maps of the downtown area were obtained from the Planning Office of the City of Buffalo, New York. From these maps, information was obtained such as street and building

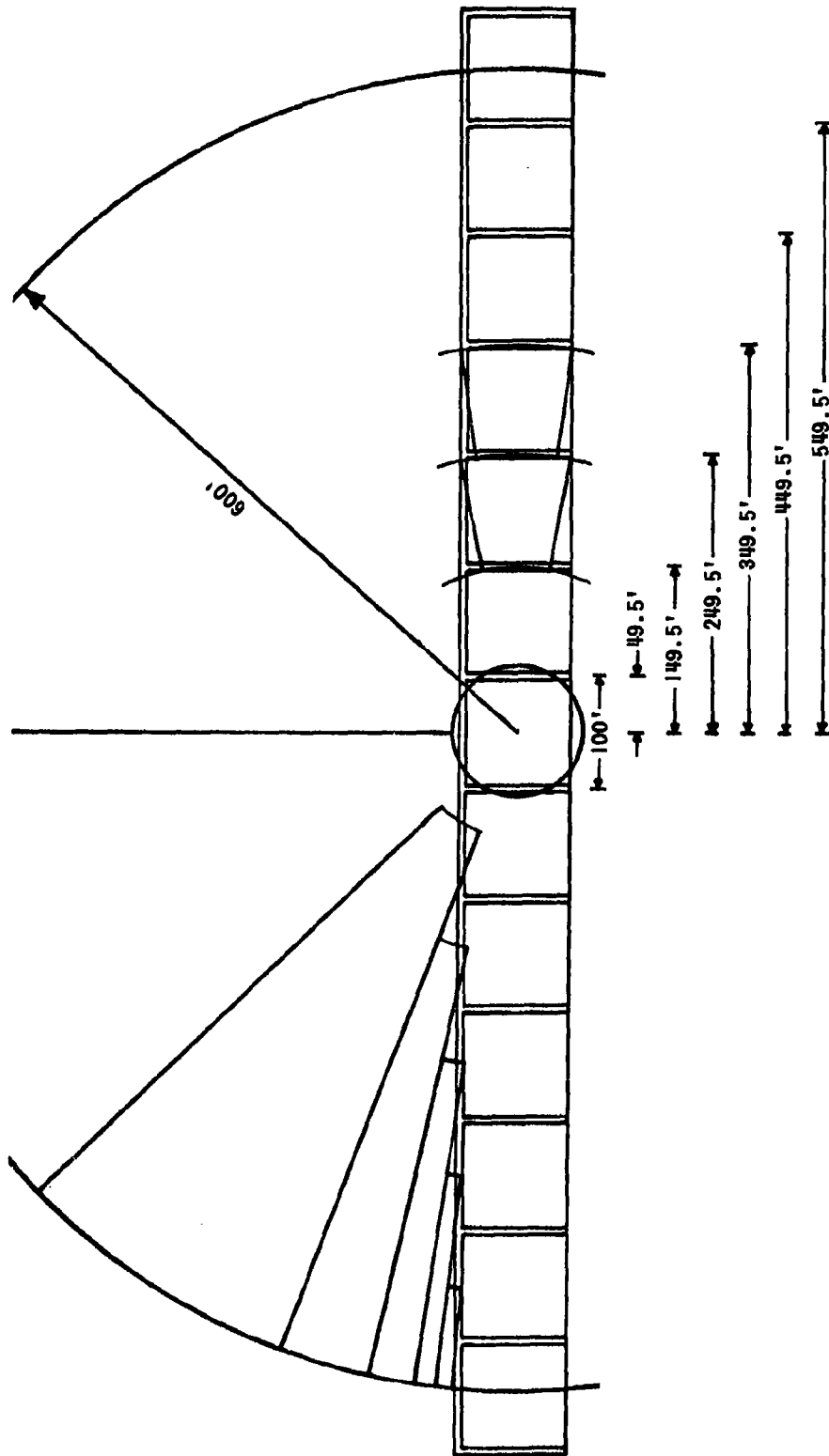


Figure 22 MAP OF SHOPPING PLAZA

dimensions, building materials, wall thicknesses and the like. Using this information, an idealized city complex was created. A four block area was considered and plan view map is shown in Figure 23. The profile views looking both north and south from the central street show the building heights, and are presented in Figure 24. The plan view shows the scheme of numbering the areas for the computations. The building material and number of stories in each building are also shown. The height of one story is taken as 12 feet. Dose rate calculations were made for five different points (floating origins) along the central street and are marked A through E. Each origin is at the center of the street, three feet above the pavement.

Computations for dose rate were made using method 3 and results are summarized in Table 11. These results are also plotted in Figure 25. In addition, the solid circles shown in this plot are those determined by subtracting from the computed dose rates 50% of the contribution to dose rate from the central street area. This is done to show how much the dose rate would be decreased by even a relatively inefficient decontamination procedure applied only to the street area. Table 12 is one of the data runs from this program given to illustrate the contributions for one of the origins (Origin A) from the individual contaminated surface areas and also showing the shielding factors used. The shielding factors (labeled "ATT.CONST." on the data runs) were determined as follows for each area: Only those slabs of attenuating material were considered which completely shielded the floating origin from the area. The thickness of the air slab for each area was determined from the distance between the origin and the closest point of the area. The horizontal slabs taken for the intermediate floors and rooftops of multi-storied buildings were taken as one foot wood equivalent regardless of the building material. By neglecting those buildings which only partially shield the origins, the computed dose rates will be on the conservative side. On the other hand, apertures such as windows, doors, etc. in buildings are neglected in the computations and these would tend to increase the dose rates.

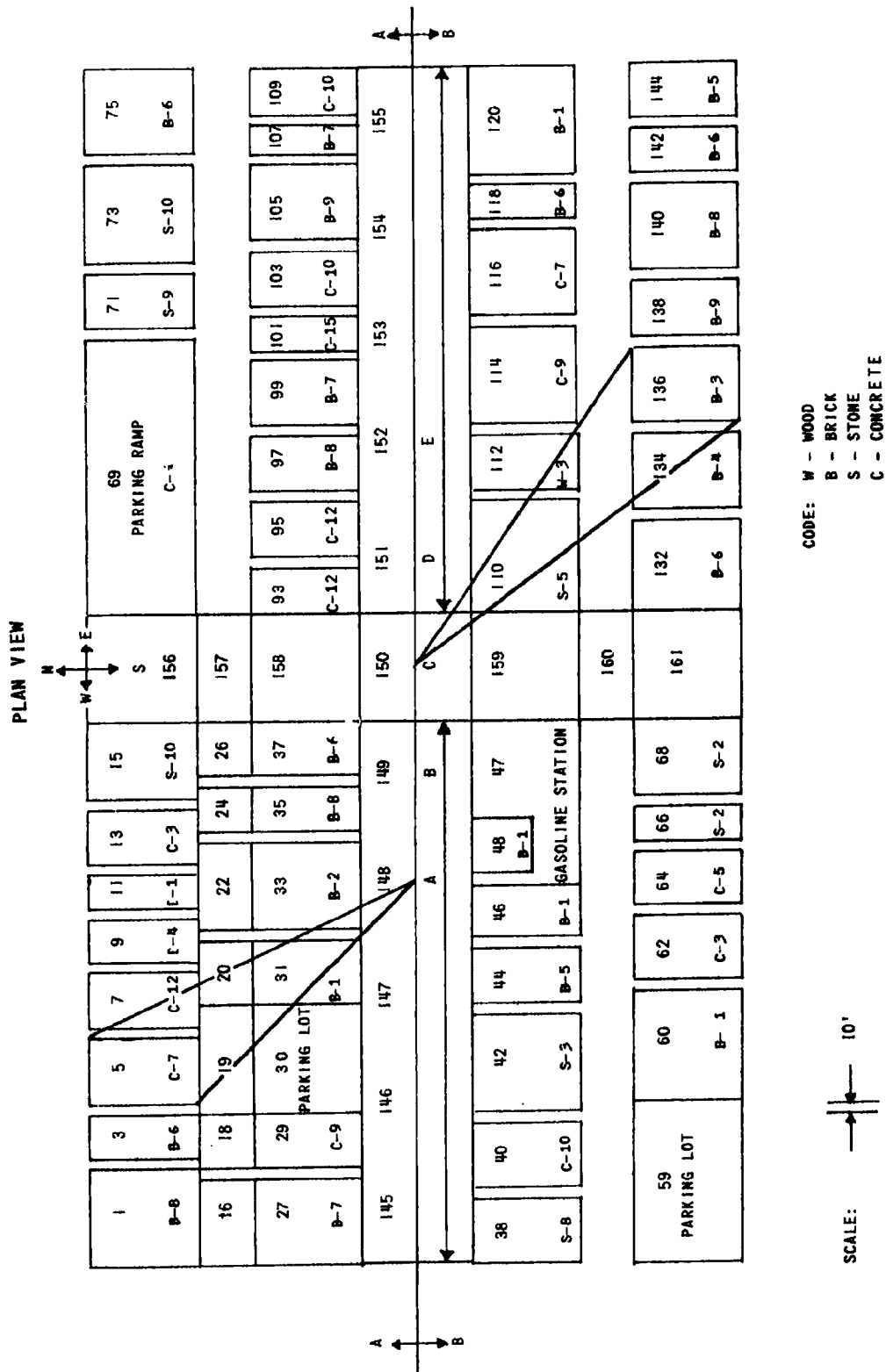


Figure 23 MAP OF CITY COMPLEX USED IN TARGET ANALYSIS PLAN VIEW

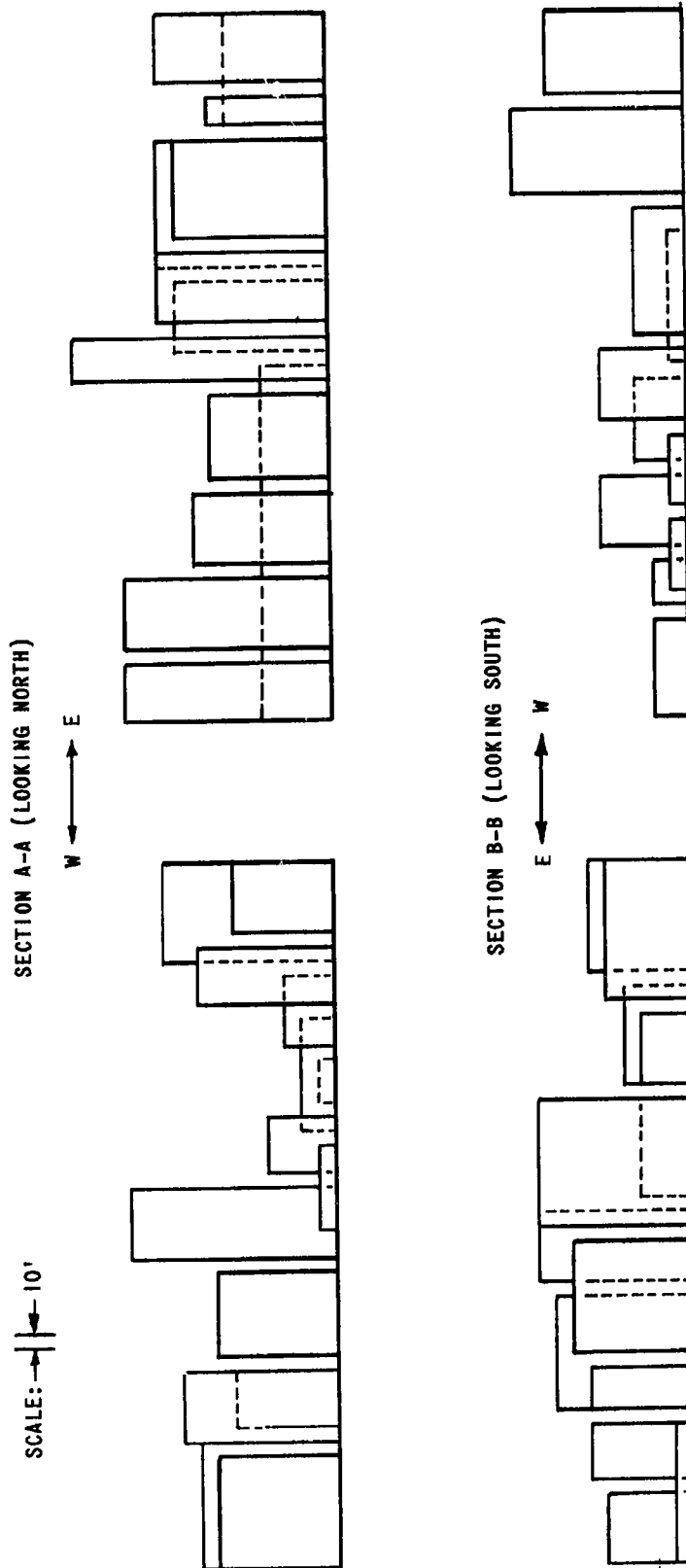


Figure 24 MAP OF CITY COMPLEX USED IN TARGET ANALYSIS
PROFILE VIEW

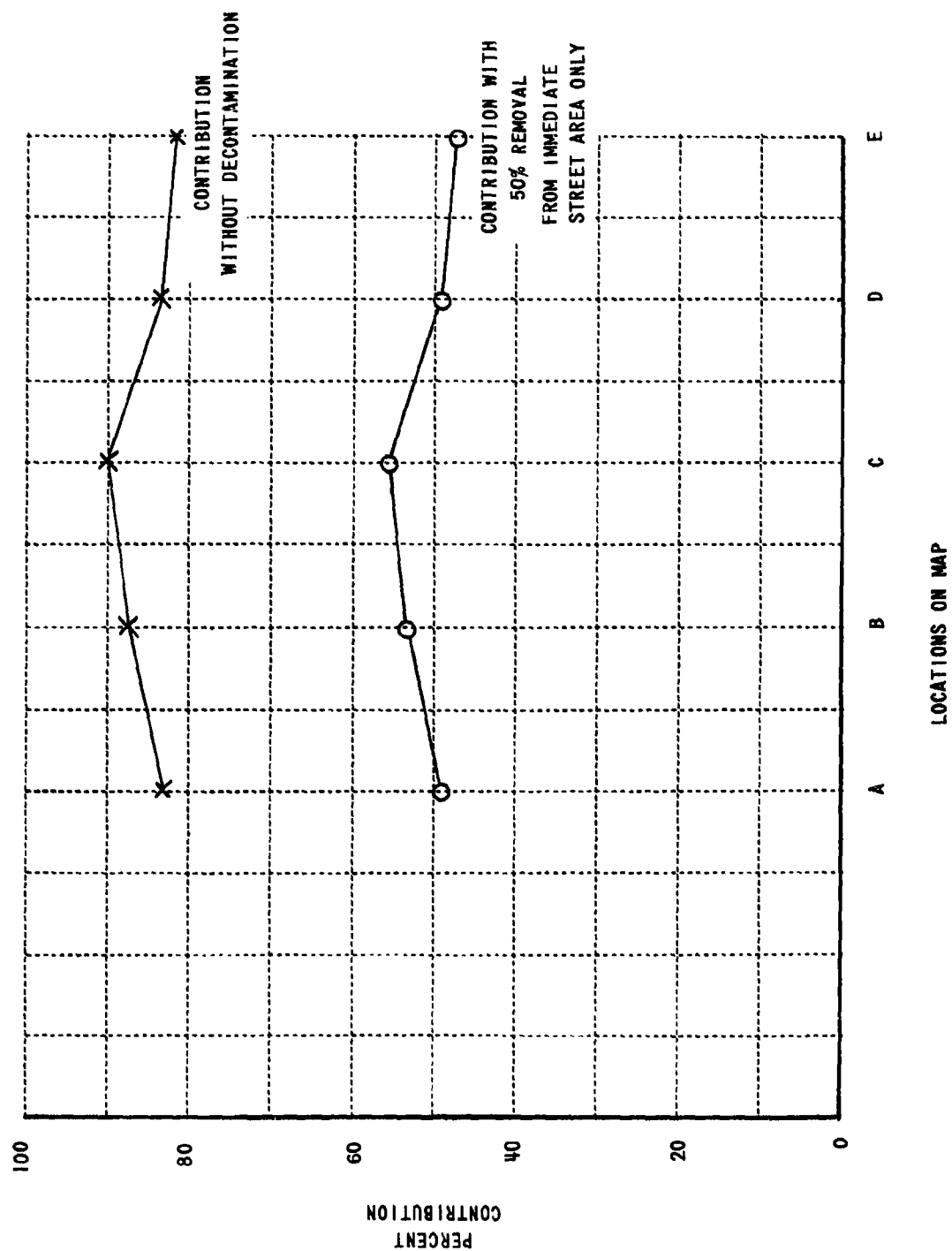


Figure 25 RELATIVE DOSE RATE ALONG CENTER OF STREET

DOSE RATE COMPUTATIONS

1. Circular Sector with Constant Attenuation

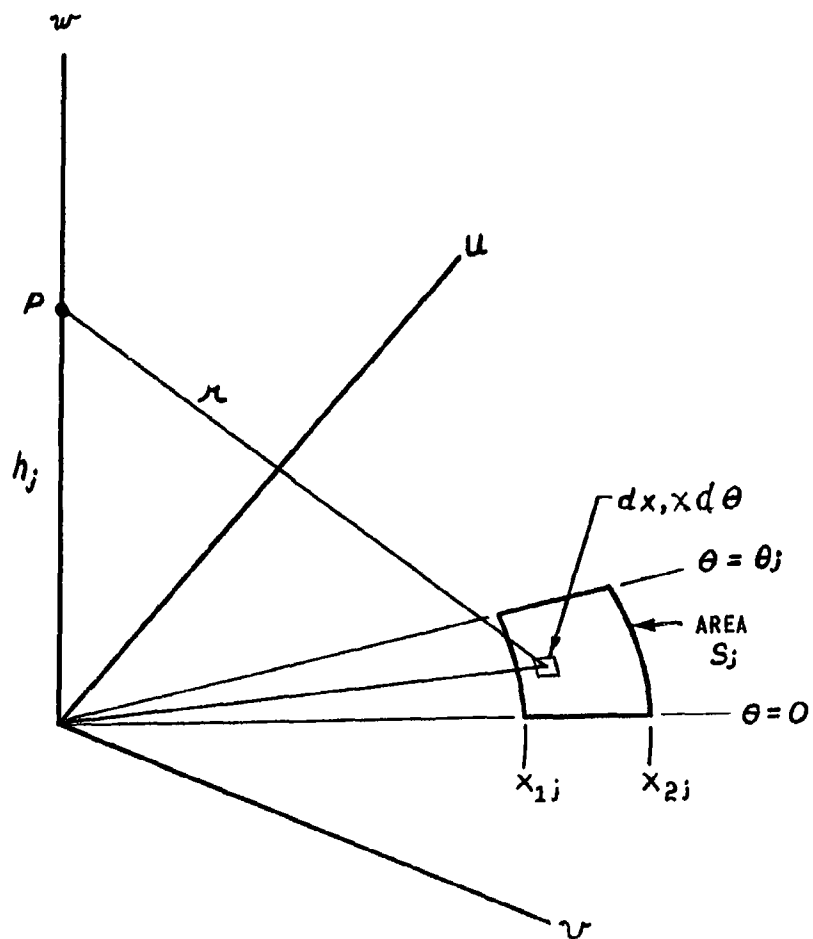


Figure 26 CIRCULAR SECTORS

- Given : (1) The area, S_j , defined as a circular sector in the uv plane with minimum and maximum radii of x_{1j}, x_{2j} respectively and subtending the angle θ_j .
- (2) The point P lying along the axis to the circular sector, S_j , a distance h_j from the uv plane.
- (3) A uniform distribution of fallout material on S_j such that the source strength of gamma ray flux in any direction is I_0 r/hr per unit area.
- (4) The area S_j is immersed in an isotropic homogeneous medium with total absorption coefficient κ .
- (5) Buildup factor $\equiv 1$

Find: The contribution to dose rate at the point P due to area S_j assuming the attenuation of radiation is constant for all points on the area.

The dose rate contribution at point P will be given by:

$$D_j = \int_0^{\theta_j} \int_{x_{1j}}^{x_{2j}} \frac{I_0 e^{-\kappa r} x dx d\theta}{r^2} \quad (8)$$

If the attenuation is constant over the region of integration, then $e^{-\kappa r} = A_j = \text{a constant and}$

$$D_j = I_0 A_j \int_0^{\theta_j} \int_{x_{1j}}^{x_{2j}} \frac{x dx d\theta}{r^2} \quad (9)$$

Also, $r^2 = x^2 + h^2$

$$r dr = x dx \quad (10)$$

and

$$D_j = I_0 A_j \int_0^{\Theta_j} \int_{\sqrt{x_{1j}^2 + h_j^2}}^{\sqrt{x_{2j}^2 + h_j^2}} \frac{dr d\theta}{r} \quad (11)$$

Integrating,

$$D_j = I_0 A_j \frac{\Theta_j}{2} \text{Loge} \left[\frac{x_{2j}^2 + h_j^2}{x_{1j}^2 + h_j^2} \right] \quad (12)$$

2. Circular Sector with Attenuation

Given: Same as method A

Find: The contribution to dose rate at the point P due to area S_j with consideration of the spatial variation of absorption.

It is now necessary to integrate 8 retaining the exponential term.
Again using the transformation 10 we get,

$$D_j = \int_0^{\Theta_j} \int_{\sqrt{x_{1j}^2 + h_j^2}}^{\sqrt{x_{2j}^2 + h_j^2}} \frac{I_0 e^{-kr} dr d\theta}{r} \quad (13)$$

Now let

$$\begin{aligned} z &= kr \\ dz &= k dr \\ D_j &= I_0 \int_0^{\theta_j} \int_{z_{1j}}^{z_{2j}} \frac{e^{-z} dz d\theta}{z} \end{aligned} \quad (14)$$

where

$$\begin{aligned} z_{1j} &= \mu \sqrt{x_{1j}^2 + h_j^2} \\ z_{2j} &= \mu \sqrt{x_{2j}^2 + h_j^2} \end{aligned}$$

Integrating with respect to θ

$$D_j = I_0 \theta_j \int_{z_{1j}}^{z_{2j}} \frac{e^{-z} dz}{z} \quad (15)$$

This integral cannot be solved in closed form. The integral can be evaluated by machine using numerical methods. For hand computations the integral in equation 15 can be expressed in terms of the exponential integral:

$$E(z) = \int_z^{\infty} \frac{e^{-t} dt}{t} \quad (16)$$

namely

$$\int_{z_1}^{z_2} \frac{e^{-z} dz}{z} = \int_{z_1}^{\infty} \frac{e^{-t} dt}{t} - \int_{z_2}^{\infty} \frac{e^{-t} dt}{t} \quad (17)$$

Values of the exponential integrals $E(z)$ are tabulated in standard tables.*

* Tables of Sine, Cosine and Exponential Integrals Works Project
Administration for the City of New York, N.B.S. 1940

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APPENDIX I

STUDY OF FEASIBILITY OF DECONTAMINATION -
ERIE COUNTY CIVIL DEFENSE EXERCISE
"OPERATION VIGILANCE 1963"
18-19 January 1963

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County Office of Civil Defense

March 1, 1963

SUMMARY

The radiation fallout pattern time history of civil defense exercise, "Operation Vigilance, 1963" is analyzed with respect to the availability of shelters for the population and the critical facilities and population areas in need of decontamination. In the southern part of the County, the natural decay of fallout will remove the need for decontamination. In the northern part, however, a general decontamination is needed to permit early re-use of large areas and large amounts of spot decontamination needed for access to and use of several critical facilities.

It was determined that decontamination was both possible and feasible. The decontamination plan consists of (1) flushing streets and roadways, (2) firehosing the roofs of structures and (3) the removal of the upper surface of ground surrounding the structures. The flushing and hosing operations could be done using available equipment, possibly supplemented by other suitably adapted apparatus. Removal of lawns or soil could be done by the dwelling or structure occupants on a regulated exposure time schedule. For the conditions existing in Operation Vigilance, 1963, in which approximately one-half of the city required decontamination treatment, the decontamination operation can be done in four to five weeks after the attack.

INTRODUCTION

As a part of the exercise "Operation Vigilance 1963" conducted by the Consolidated Erie County Office of Civil Defense, a study was made of the problems involved in and the feasibility of decontaminating the areas affected by fallout. Since this exercise was based on the problems caused only by fallout from bombs assumed to have landed outside of Erie County, the additional complications that would have arisen in decontamination procedures in the presence of blast and fire damage were taken not to be applicable to this study.

The problem studied was to answer such questions as "what can be done to decontaminate access routes to critical facilities and to decontaminate the facilities themselves; and when can it be begun?", and "what is the feasibility of decontaminating the worst areas to advance the allowable date of reoccupancy?". To answer these questions, it was necessary to use the best available information on decontamination techniques. Data from Refs. 1 and 2 were used, with modification to compensate for difficulties that would be encountered in actual practice. Examples of such difficulties are: transporting of water from the nearest hydrant or other source; the routing of the decontamination apparatus, and allied problems required by the necessity that street flushing proceed from higher to lower elevations; the effects of abandoned vehicles in the streets; and the problems of frequently changing decontamination crews to avoid their overexposure. These complexities were assumed to result in average values of miles of street decontamination/vehicle/hour which are far less than actual vehicle velocities while flushing.

The admissible dosage for individuals is a determining factor in several respects, such as: (1) the time when a structure can be reoccupied without decontamination, (2) the completeness of decontamination needed, and (3) the levels of ambient radiation under which decontamination crews can operate for durations of practicable usefulness. This study is based on the assumption that the admissible individual dosages (in the worst cases) are 30 Roentgens in a day, 230 R in two weeks, or 1000 R during a year. These values, which are relatively high compared to the values often used in studies of community health problems, are based on Refs. 1 and 3. They must be

considered to be emergency values for volunteer crews, since some individuals among the crews which receive the maximum admissible doses under these regulations will suffer immediate illness and/or permanent effects. However, examination of the results of this study and consideration of the consequences of the much greater fallout possible in heavier raids indicates that the values used are probably representative of what would be used in actual circumstances.

In performing this study, the information available from several sources was used. The fallout patterns were made available by the Radiological & Chemical Officer of the Civil Defense Office; maps, the comprehensive data on shelter locations and capacities, and the data on equipment available were provided by the Civil Defense Office Headquarters staff; and the "Operation Vigilance 1963" reports of the following services were made available and found very helpful:

Medical	Fire	Training
Welfare	Police	Northwest Zone
Resources and Production	Manpower	Northeast Zone

In addition, the experience generated at Cornell Aeronautical Laboratory in performing the Office of Civil Defense Project "Radiological Target Analysis Procedures" was most helpful; and the writers wish to express appreciation for permission of the Laboratory to participate in "Operation Vigilance" and for assistance in publishing this report.

SITUATION - OPERATION VIGILANCE 1963

At 1800 hours (6:00 pm) on 18 January 1963, a one megaton surface blast bomb was assumed to have fallen on the north end of Grand Island. A NW wind was assumed to have carried the fallout from this bomb into Erie County. A similar bomb near Erie, Pa. an hour later was also assumed but with little effect on Erie County. These bombs were assumed to have negligible blast and heat effects in Erie County.

As shown in Figure A-1, at H + 1 hour a zone of intense fallout (3000 R/hr at edge of zone and up to 10,000 R/hr or more in center) about three miles wide which, in Erie County, extended from the Niagara River

between the South Grand Island Bridge and the Town of Tonawanda, across the Village of Kenmore, North East Buffalo, and Eggertsville, over the middle third of the Town of Cheektowaga and into the western half of the Village of Depew. In the surrounding area, the intensity at this time decreased steadily to 1000 R/hr along a line running from the Peace Bridge, southeastward through downtown Buffalo and Cazenovia Park, eastward through Ebenezer and the Town of West Seneca, then swinging northward through Alden and finally northwestward through the intersection of Main and Sheridan and into North Tonawanda.

At H + 49 hours, these boundaries had reduced from 3000 and 1000 R/hr to 30 and 10 R/hr respectively. At H + 2 weeks, these boundaries were 3 and 1 R/hr. In the very intense core, an oval area about three miles wide and 9 miles long in the NW/SE direction and centered at the University of Buffalo had intensities of 100 R/hr or more at H + 49 hours and 10 R/hr or more at H + 2 weeks.

SHELTERS - COMMENTS

This exercise assumed that everyone had entered an available shelter with a radiation attenuation factor of at least 100. However, it should be pointed out that in actuality, this would not have been the case for two reasons. The first is that the hardest hit area is largely residential, having a very few large buildings. Thus, with the very small number of adequate home shelters now in existence and with most of the public shelters located in the larger buildings in the downtown and industrial areas (see Figure A-2), few of the people in the hardest hit area would have been able to reach adequate shelters. It is also pertinent to note that at 6 pm when the bomb fell, most of the population would have been at home. The second reason is that in the NW portion of Erie County, many of those persons out of doors at the time of the blast would have faced toward the blast and in most weather conditions, may have been temporarily blinded. Without assistance from others, they would not have been able to reach shelters.

The assumption is more representative of the probable case in the remainder of the County, especially where more public shelters are available, and where the fireball would have been more distant and lower on the horizon, so that intervening trees and buildings would have obscured much of the glare. However, even in this area, it is highly questionable if a sufficient number of adequate home and neighborhood shelters could have been reached in time under the present conditions of public awareness of the problem and knowledge of the location of the nearest adequate shelter. Based on estimates received from the Radiological Service combined with population estimates for the area covered by the fallout, the Medical Service report arrived at the following estimate of casualties from radiation: "Assuming that 400,000 persons living in the high fallout area were able to reach shelters with protection factors of 100, it was expected that there would be 20,000 deaths, 200,000 mild to severe cases of radiation illness and 180,000 not affected. In the event that there were people not in shelters at the time the fallout descended the degree of radiation injury would depend on the time spent outside the shelter before the person reached shelter." The limitation of shelters with factors of only 100 in a high fallout area is apparent.

These considerations are, in actuality, outside the province of this report. However, they became so startlingly clear during the conduct of this study that a comment on them was felt to be warranted here.

NEEDS FOR DECONTAMINATION

The need for decontamination can be seen from the following data. Taking as allowable limits the criteria that an individual should not receive more than 30 R/day, 230 R in two weeks, or 1000 R in a year (or lifetime), a person with no previous exposure (i. e., having spent all of the time since the start of fallout in a perfect shelter), could at about H + 10 days safely reoccupy buildings in an area which had had 1000 R/hr at H + 1 hour. However, the corresponding times for safe reoccupation of buildings in an area having 1500 R/hr at H + 1 hour would be H + 3 weeks; for areas subjected to 3000 R/hr at H + 1 hour, the allowable entry time for permanent residence would be 2-1/2 months; and for 10,000 R/hr at H + 1 hour, the waiting period would be 7 months.

It can be seen from Figure A-1 that in the southern portion of the County it would be possible to leave the shelters and resume more or less normal occupancy in periods ranging from a few days to a few weeks. Within this period, some local decontamination would be required to allow the resumption, or continued operation, of essential services and utilities (fire, police, electricity, water, gas) and to provide access to and operation of hospitals and aid stations. In addition, there would be a desire to provide access to shelters and local fires and to permit transport and delivery of fuel oil, gasoline, and possibly some food.

Shelters are stocked for two weeks. Also, the radiation decay rate is such that there is nothing to be gained by moving a person from an inadequate shelter to an adequate one after, say, 48 hours. Therefore, in the southern part of the county there would be little urgent need for access to the shelters during the first two weeks. General decontamination will not be required in this area. Because of the large area involved, the time that would elapse before it became possible to emerge to start decontamination and the relatively short time during which general area decontamination would be needed in the southern part of the County, it is likely that in most instances the natural decay of the fallout will remove the need for such decontamination before it would be feasible to attend to it.

In the northern part of the county, however, Figure A-1 illustrates that approximately 20 sq. miles are contained in the hottest area where initial radiation appeared to be as high as 10,000 R/hr., another 50 square miles in the area affected by 3000 to 10,000 R/hr and 70 more square miles in the range 1500 to 3000 R/hr. If no decontamination were to take place in these areas, if the occupants were housed in perfect shelters (infinite radiation attenuation factors) and if the shelters could be restocked, the population might wait in the shelters for the required periods (7 months to 3 weeks) before reoccupying their homes and business in the normal way. If shelters with attenuation factors of about 100 were used, the times required before use of the shelters could be discontinued would be longer. Also, some deaths and

much radiation sickness would have occurred and there would be urgent need for a large amount of evacuation (especially in the 10,000 R/hr at H + 1 area).

However, where the shelters are adequate, it is possible that, at the expense of extending the total duration of shelter occupancy somewhat, the occupants could, after a few days or weeks (depending on the situation), leave them for short periods each day. The permissible periods would depend on how much radiation they had received up to that time and the rates that would be encountered both inside and outside of the shelter in the future. Thus, with restocking and other assistance, many occupants in the most hard hit areas might continue to occupy the shelters in their area and participate in the decontamination of their own property. But, the times of occupancy would be long, for cramped quarters, and the determination of the allowable time out of the shelter would be complicated - varying from location to location and with the radiation history of each individual (especially where home shelters with varying attenuation factors are used) - so that its computation and regulation probably may be impractical.

In any event, extensive evacuation of shelter occupants in these areas at the earliest possible date may be necessary. Also, the 10,000 R/hr and 3000 R/hr areas would require extensive general area decontamination if the populations in them are to be allowed to reoccupy their buildings within a reasonable time.

In addition to the necessary general decontamination to permit early re-use of large areas, a large amount of spot decontamination would be needed in these areas. Access to and use of several facilities in this area is needed at the earliest possible date. These facilities include a major electrical power generating station, two major hospitals, a number of water intakes and storage facilities, several gas storage tanks and petroleum processing and storage areas, and several universities and colleges, in addition to numerous police and fire stations. Further, the contaminated area cuts across all of the major routes of communication between Buffalo and Niagara Falls. Finally, if the occupants of the shelters are to be evacuated or restocked, pending the completion of decontamination operations, access to the shelters is necessary.

DECONTAMINATION - TECHNIQUES AND FEASIBILITY

Decontamination techniques and equipment required have been developed and reported upon in Refs. 1-5. Experimental tests have been conducted indicating the effectiveness of various types of equipment, such as nozzles and tank pumping apparatus, and the operating procedures and conditions under which they would be used. From the results indicated in reports 1-5, decontamination could successfully be accomplished by (1) flushing of roadways; (2) washdown of roofs; and (3) removal of lawns or upper few inches of soil. It is shown in these references that effective removal of fallout type particles can be achieved on roadways and roofs by using highway flushers and/or fire hoses, provided that certain practicable flow rates and pressures are used and that the correct flushing techniques are employed. In structures where the upper one or two levels could be closed off and left vacant for six to seven months, washdown of the roof sometimes may be dispensed with.

There are roughly 40 miles of roadway per square mile in heavily populated areas and 10 miles per square mile (or less) in semi-rural areas. The hot areas are approximately evenly divided between both types of areas. Thus, there are 3500 miles of roadway to be flushed. Considering traffic difficulties (abandoned cars on the roadway), loading of water, travel between work and water supply (fire hydrants), changing of crews in a safe place, a water flusher equipped with the required nozzles and apparatus is expected to clean one mile of roadway each hour. If we have 10 flushers in the area, this implies that there are 350 hours of work for each of them (or two weeks working around the clock). If the rate of flushing achieved is faster, then less effort will be required. Now, if the minimum useful period of a crew to work is one hour, operations could begin one day (24 hours) after attack in the area where radiation is 1500 R/hour* and could progress inwards into the hot areas. Start times are two days or later for the 3000 R/hour* area and 5 days for the 10,000 R/hour* zones. By working inwards toward the hottest zone, these start times can be complied with. A report from the Resources and Production Service** indicates that it would be impractical to use any of the vehicles in the Transportation Service (such as tank trucks, tractors, etc.) for a period of

* Radiation at one hour I (1).

** A technical group associated with Erie County Civil Defense.

H to H + 7 days.* From H + 7 to H + 28, it is possible to decontaminate this equipment so that by the end of that period all resources would be available. The number of vehicles are much greater than the ten vehicles assumed in the above analysis but further investigation is needed to determine the number equipped with suitable apparatus for the task.

Fire-house crews could perform roof-washdown immediately after the road-flushers. They would, of course, be limited by the same work time limit (one hour at the start) as the road-flusher crews. If a fire-hose crew spends 5 minutes on each roof washdown, then 17 crews are required to follow each road flusher or 170 crews each hour.** The flushing crews may consist of members chosen from the public, supervised by one member from the fire department so that fire-department personnel will be available for the entire operation.

Whereas decontamination of roadways and roofs require somewhat special equipment and experienced manpower to at least direct the operation, the decontamination of the ground around each dwelling or structure could be done by each individual occupant. The operation would consist of removing the top few inches of lawn or soil and depositing it at the back or remote part of the yard and covering it with about a foot of dirt. The bare essentials for equipment would be shovels and wheelbarrows.

For the sake of efficiency, residents might form teams so that some work the shovels and others the barrows. It is estimated that each man can remove five square feet of sod per minute or 300 square feet per hour. If each lot contains 10,000 square feet, then 33 hours of labor are required. This work may be divided into 5-1/2 days of 6 hours each. The entry time for a 6-hour shift is 5 days for the 1500 R/hr zone, 10 days for the 3000 R/hr zone, and 24 days in the 10,000 R/hr zone. Therefore, by the end of 4 or 5 weeks after impact enough general decontamination can have taken place to allow people to resume normal activities. Direction would have to be provided to each occupant or worker for the allowable time or frequency he should be able to remain out of the shelter depending on the radiation history. The task of decontamination of ground areas could be done more efficiently if earth moving equipment and operating manpower were available and the area was accessible to this type of equipment. Narrow strips or small areas cannot accommodate the large machine equipment or spacing between dwelling may restrict the machines from access to rear areas. There are, however, many types and sizes of machines of the garden tractor variety that could be used in small areas.

* An assumption for this experiment.

** Based on 50 ft lots, thus 100 houses/mile each side of street - or 200 houses/mile on both sides of street.

Instead of removing and depositing radioactive ground in back areas, it may be more feasible in some cases to dispose of the ground similar to a snow removal operation. A further study of all the types and sizes of available equipment that could be adapted to the task is necessary.

Some areas like hospitals and utilities need to be decontaminated very early. If the utilities can be operated without extensive human supervision, it would be best to defer decontamination for at least 48 hours in the 3000 R/hr area and 5 days in the 10,000 R/hr area, i. e., until it is possible to work a crew at least an hour. Fortunately, many of these structures are massive and portions of them constitute fallout shelters. Therefore, in many instances, an operating crew will be available on the premises to perform brief tasks of maintenance and adjustment as soon as the radiation level permits some egress. Emergency decontamination around hospitals and critical tasks at utilities might proceed as soon as a 10-minute opportunity is available, i. e., 11 hours after attack for the 3000 R/hr area and 28 hours in the 10,000 R/hr area. It is important that personnel who will perform the work are prepared to be very efficient because at 10 minutes per man, many men will be needed. The eventual decontamination around hospitals in the "hot" area should endeavor to remove contaminant up to a distance of 300 ft. Cleanup should be quite meticulous near the building, but does not need to be quite so careful farther away. Furthermore, roof washdown will be required unless it is feasible to vacate the upper two or three floors of the hospital. Until the decontamination has been completed, patients will have to be well sheltered.

INFLUENCE OF WEATHER

The foregoing analysis was performed using data applicable to fair weather with temperatures above freezing. The exercise being considered here took place in January and Western New York encounters several months of freezing weather each year.

From the nature of the operations involved, it appears that if a snow cover existed at the time of fallout and was not deeply covered by additional snow before decontamination began, techniques for removal of the snow from streets, roofs and yards would suffice. In this case, the snow (or at least the top few inches of it) would have to be removed to a remote area, not just plowed to the side. Clearly, a brief thaw or a heavy snowfall before decontamination could begin would seriously complicate matters, as would situations of drifting snow. In extreme cases, any general decontamination would have to be deferred until Spring.

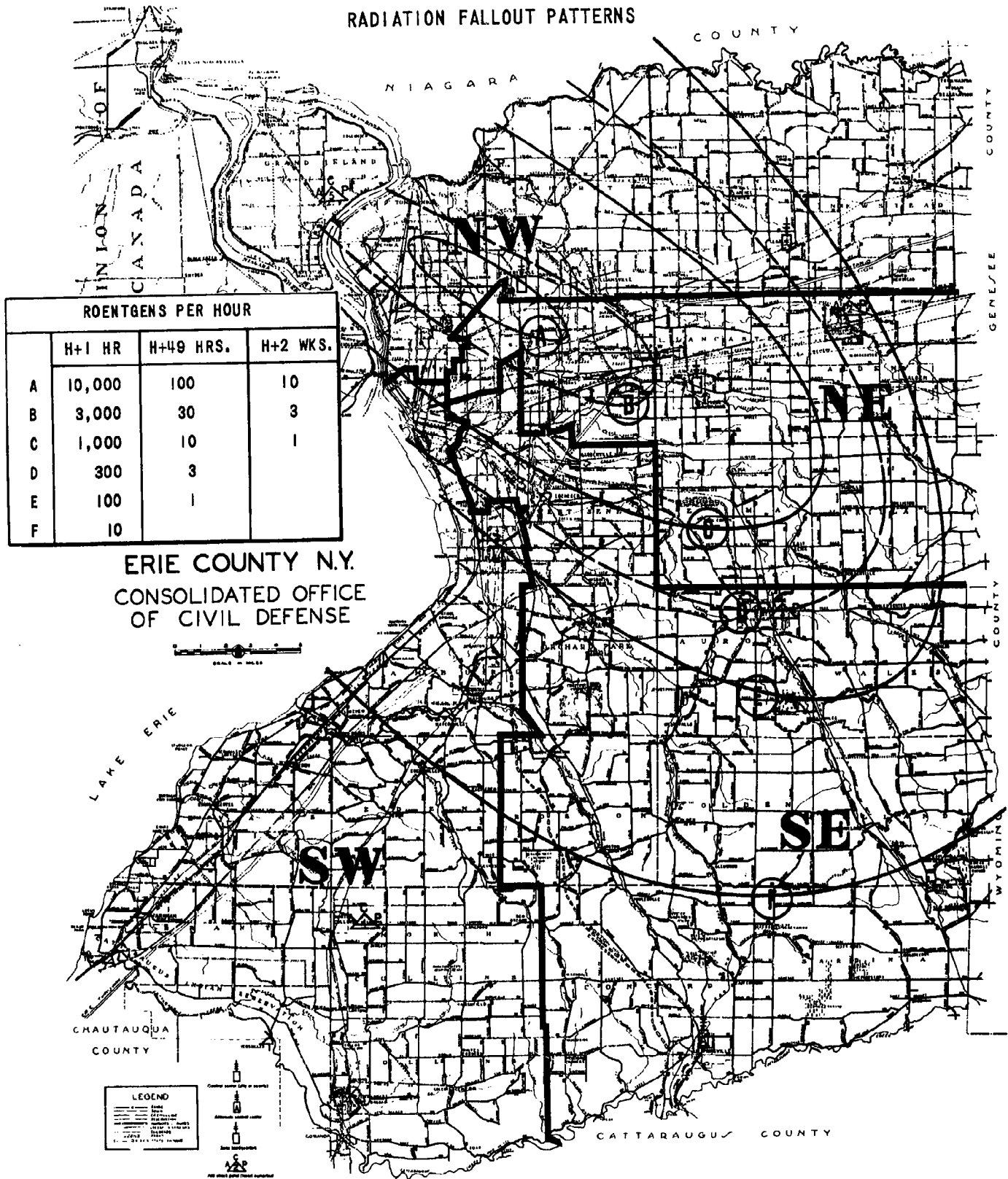
In the event of cold weather without a snow cover, an even less hopeful situation would exist. Tests with street sweepers and vacuum cleaners have shown less favorable results (Ref. 1), providing less complete and less efficient removal. However, in cold dry weather, such methods would have to be used to the extent possible. Streets, sidewalks and paved areas could be swept or vacuumed, flat lawns might be vacuumed. At present, there appears to be no practicable method for treating large areas of roofs or rough ground during such weather.

One favorable aspect of weather is the effect of rain. A heavy shower, subsequent to the initial fallout, would wash most of the particles containing radioactive materials off sloping roofs and crowned roads. Some of the material would be washed into sewers, other portions into gutters. Subsequent decontamination efforts would be simplified appreciably.

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 NAVDOCKS TP-PL-13.

RADIATION FALLOUT PATTERNS



1960 CENSUS (TOTAL 1,060,688)		City of Tonawanda 21,561	
City of Buffalo 532,759	City of Lackawanna 29,564		
<u>VILLAGES</u>		<u>TOWNS</u>	
Alden 2,042	Windsor 3,990	Alden 7,515	Collins 6,954
Williamsville 4,315	Hamburg 9,145	Amherst 62,937	Concord 6,452
East Aurora 6,791	Depew (part) 6,221	Aurora 12,400	Eden 6,650
Parnham 422	Lenox 12,254	Boston 5,100	Elma 7,400
Depew (part) 7,459	Albion 2,561	Brant 2,290	Evans 12,078
Albion 5,803	North Collins 1,574	Cheektowaga 84,055	Grand Island 9,607
Owens (part) 1,079	Orchard Park 3,724	Clarence 13,767	Hamburg 41,258
Springville 1,052	Hammar 21,261	Colden 2,304	Holland 2,304
Angola 2,499			

Figure 1a

AVAILABLE SHELTER DISTRIBUTION

COUNTY

AREA	SHELTER CAPACITIES
A	192,800
B	29,900
C	41,200
D	20,800
E	11,800
F	630
G	2,080
H	630
I	3,000
J	300
K	810
L	2,330
M	1,980

ERIE COUNTY N.Y.
CONSOLIDATED OFFICE
OF CIVIL DEFENSE

LAKE ERIE

CHAUTAUQUA COUNTY

LEGEND

City of Buffalo 532,759

1960 CENSUS (TOTAL 1,054,688)

City of Lackawanna 29,564

City of Tonawanda 21,581

VILLAGES

Alden	2,062	Blasdell	3,709
Williamsville	4,316	Hamburg	9,185
East Aurora	6,791	Dapew (part)	6,221
Parham	422	Lancaster	12,294
Dapew (part)	7,359	Akron	2,081
Rioen	5,803	North Collins	1,574
Gowanda (part)	1,079	Orchard Park	1,278
Springville	3,852	Reiner-	21,261
Angola	2,419		

Alden	7,615	Collins	5,984
Adverset	62,137	Concord	6,452
Aurora	12,030	Eden	6,630
Boston	5,106	Elm	7,660
Beant	2,290	Gene	12,078
Chesktowage	86,056	Grand Island	4,607
Clarence	13,267	Hamburg	41,286
Colden	2,304	Holland	2,304

TOWNS

Lancaster	25,605
Marilla	2,252
Newstead	5,925
North Collins	3,805
Orchard Park	15,078
Sardinia	2,145
Tonawanda	135,032
Wales	1,110
West Seneca	33,646

Figure 2a

APPENDIX II

Digital Computer Results for Target Area Shielding Analysis

(These data illustrate the methods of
computation and are discussed in
Chapter VIII)

Table 5

CIRCULAR DISCS

SECTOR GEOMETRY METHOD WITH ATTENUATION

PROJECT RADTAP (W/A-E12-110) --- J.RINALDO, DEPT. 4707

RELATIVE DOSAGE COMPUTATIONS ---

DOSE RATES FROM CIRCULAR DISCS OF VARIOUS RADII

CIRCULAR SECTOR METHOD WITH ATTENUATION

LOCATION OF COORDINATE ORIGIN IS THREE FEET ABOVE CENTER OF CIRCULAR DISC AIR ATTENUATION

PARAMETERS ---

D SUB INFINITY = 2.5309E 01

NUMBER OF AREAS = 28

INTEGRATIONS VIA ADAMS-MOULTON VARIABLE INCREMENT METHOD

AREA NO.	AREA IDENTIFICATION	H (FT)	R ONE (FT)	R TWO (FT)	THETA (RAD)	DOSE	PERCENTAGE OF D. INF.
1	CIRCULAR DISC OF RADIUS R2	3.000	0.	10.000	6.28368	7.67939E 00	20.3425
2		3.000	0.	20.000	6.28368	1.14438E 01	45.2362
3		3.000	0.	30.000	6.28368	1.39360E 01	25.0714
4		3.000	0.	40.000	6.28368	1.55223E 01	61.3706
5		3.000	0.	50.000	6.28368	1.67315E 01	66.1090
6		3.000	0.	60.000	6.28368	1.76799E 01	59.8562
7		3.000	0.	70.000	6.28368	1.84558E 01	72.9221
8		3.000	0.	80.000	6.28368	1.91061E 01	75.4914
9		3.000	0.	90.000	6.28368	1.96606E 01	77.6822
10		3.000	0.	100.000	6.28368	2.01403E 01	79.5775
11		3.000	0.	120.000	6.28368	2.09301E 01	82.6984
12		3.000	0.	140.000	6.28368	2.15543E 01	85.1646
13		3.000	0.	160.000	6.28368	2.20596E 01	87.1617
14		3.000	0.	180.000	6.28368	2.24763E 01	88.8077
15		3.000	0.	200.000	6.28368	2.28247E 01	90.1840
16		3.000	0.	250.000	6.28368	2.36822E 01	92.7820
17		3.000	0.	300.000	6.28368	2.39357E 01	94.5740
18		3.000	0.	350.000	6.28368	2.42395E 01	95.8531
19		3.000	0.	400.000	6.28368	2.44962E 01	96.7884
20		3.000	0.	450.000	6.28368	2.46723E 01	97.4844
21		3.000	0.	500.000	6.28368	2.48055E 01	98.0104
22		3.000	0.	550.000	6.28368	2.49071E 01	98.4122
23		3.000	0.	600.000	6.28368	2.49855E 01	98.7219
24		3.000	0.	700.000	6.28368	2.50940E 01	99.1506
25		3.000	0.	800.000	6.28368	2.51610E 01	99.4154
26		3.000	0.	900.000	6.28368	2.52031E 01	99.5814
27		3.000	0.	1000.000	6.28368	2.52299E 01	99.6875
28		3.000	0.	10000.000	6.28368	2.52807E 01	99.8883

Table 6

SECTOR GEOMETRY METHOD WITH ATTENUATION

CYLINDRICAL FARM HOUSE

PROJECT RADTAP (W/AFETZ-110) — J. RINALDO, DEPT. 4767

RELATIVE DOSE RATE COMPUTATIONS — DOSE RATE CALCULATIONS FOR CYLINDRICAL FARMHOUSE ON CIRCULAR DISC

COMPUTED FOR VARIATIONS IN PARAMETERS

LOCATION OF COORDINATE ORIGIN IS CENTER OF FARMHOUSE THREE FEET ABOVE FLOOR

PARAMETERS —

D SUB INFINITY = 2.5309E 01 NUMBER OF AREAS = 42

INTEGRATIONS VIA ADAMS-FOULTON VARIABLE INCREMENT METHOD

AREA NO.	AREA IDENTIFICATION	H (FT)	R CORE (FT)	R TRO (FT)	THETA (RAD)	DOSE	PERCENTAGE OF D INF
1	ROOFTOP (VARIOUS RADII) 2 INCH WOOD	7.000	0.	20.000	6.28368	6.20707E 00	24.5252
2	OUTSIDE AREA	3.000	20.000	600.000	6.28368	1.07361E 01	42.4203
3	ROOFTOP 2 INCH WOOD WALLS	7.000	0.	30.000	6.28368	8.00011E 00	31.6097
4	OUTSIDE AREA	3.000	30.000	600.000	6.28368	9.24328E 00	35.5217
5	ROOFTOP 2 INCH WOOD WALLS	7.000	0.	40.000	6.28368	9.20432E 00	36.3676
6	OUTSIDE AREA	3.000	40.000	600.000	6.28368	8.09833E 00	31.9978
7	ROOFTOP 2 INCH WOOD WALLS	7.000	0.	50.000	6.28368	1.02473E 01	40.4886
8	OUTSIDE AREA	3.000	50.000	600.000	6.28368	7.18428E 00	28.3653
9	ROOFTOP 2 INCH WOOD WALLS	7.000	0.	60.000	6.28368	1.09332E 01	43.1988
10	OUTSIDE AREA	3.000	60.000	600.000	6.28368	6.43207E 00	25.4141
11	ROOFTOP (VARIOUS HEIGHTS) 2 IN. WOOD	12.000	0.	30.000	6.28368	9.24328E 00	21.4723
12	OUTSIDE AREA	3.000	30.000	600.000	6.28368	9.24328E 00	36.5217
13	ROOFTOP 2 INCH WOOD WALLS	17.000	0.	30.000	6.28368	3.86252E 00	15.2614
14	OUTSIDE AREA	3.000	30.000	600.000	6.28368	9.24328E 00	36.5217
15	ROOFTOP 2 INCH WOOD WALLS	22.000	0.	30.000	6.28368	2.84340E 00	11.2347
16	OUTSIDE AREA	3.000	30.000	600.000	6.28368	9.24328E 00	36.5217
17	ROOFTOP 2 INCH WOOD WALLS	22.000	0.	50.000	6.28368	4.75320E 00	18.7807
18	OUTSIDE AREA	3.000	50.000	600.000	6.28368	7.18428E 00	28.3653
19	ROOFTOP 2 INCH WOOD WALLS	27.000	0.	30.000	6.28368	2.15156E 00	8.5012
20	OUTSIDE AREA	3.000	30.000	600.000	6.28368	9.24328E 00	36.5217
21	ROOFTOP 2 INCH WOOD WALLS	32.000	0.	30.000	6.28368	1.66635E 00	6.5839
22	OUTSIDE AREA	3.000	30.000	600.000	6.28368	9.24328E 00	36.5217
23	ROOFTOP (VARIOUS WALLS) 4 INCH WOOD	7.000	0.	20.000	6.28368	5.78350E 00	22.6510
24	OUTSIDE AREA	3.000	20.000	600.000	6.28368	9.20209E 00	35.6452
25	ROOFTOP 4 INCH WOOD WALLS	7.000	0.	30.000	6.28368	7.33687E 00	28.9971
26	OUTSIDE AREA	3.000	30.000	600.000	6.28368	7.94227E 00	31.9012
27	ROOFTOP 4 INCH WOOD WALLS	7.000	0.	40.000	6.28368	8.43700E 00	33.3360
28	OUTSIDE AREA	3.000	40.000	600.000	6.28368	7.06448E 00	27.4120
29	ROOFTOP 4 INCH WOOD WALLS	7.000	0.	50.000	6.28368	9.14349E 00	36.1274
30	OUTSIDE AREA	3.000	50.000	600.000	6.28368	6.39624E 00	25.0355
31	ROOFTOP 4 INCH WOOD WALLS	7.000	0.	60.000	6.28368	9.64701E 00	38.1169
32	OUTSIDE AREA	3.000	60.000	600.000	6.28368	5.72114E 00	22.6031
33	ROOFTOP 6 INCH WOOD WALLS	7.000	0.	20.000	6.28368	5.39159E 00	21.3031
34	OUTSIDE AREA	3.000	20.000	600.000	6.28368	7.17022E 00	30.7014
35	ROOFTOP 6 INCH WOOD WALLS	7.000	0.	30.000	6.28368	6.74102E 00	26.6349
36	OUTSIDE AREA	3.000	30.000	600.000	6.28368	6.59418E 00	27.4284
37	ROOFTOP 6 INCH WOOD WALLS	7.000	0.	40.000	6.28368	7.64335E 00	30.2001
38	OUTSIDE AREA	3.000	40.000	600.000	6.28368	6.24021E 00	24.6261
39	ROOFTOP 6 INCH WOOD WALLS	7.000	0.	50.000	6.28368	8.19174E 00	32.3669
40	OUTSIDE AREA	3.000	50.000	600.000	6.28368	5.66900E 00	22.2564
41	ROOFTOP 6 INCH WOOD WALLS	7.000	0.	60.000	6.28368	8.56159E 00	33.8283
42	OUTSIDE AREA	3.000	60.000	600.000	6.28368	5.12815E 00	20.2622

TOTAL RELATIVE DOSE = 3.0509E 02

#1205.444 PER CENT OF BACKGROUND RADIATION

Table 7
RESIDENTIAL AREA FIXED ATTENUATION

PROJECT RADIAP (N/A-E12-110) --- J. RINALDO, DEPT. 470/ RELATIVE DAMAGE COMPUTATIONS --- TEST CASE --- RESIDENTIAL AREA (HAND CHECK) --- RUN BA LOCATION OF COORDINATE ORIGIN IS CENTER OF HOUSE 3 FEET ABOVE FLOOR J. D. RINALDO									
PARAMETERS --- SUR INFINITY = 2.5309E 01 NUMBER OF ATTEN = 4P									
AREA NO.	AREA IDENTIFICATION	HIFT (FT)	0 ONE (FT)	2 TWO (FT)	THETA (RAD)	MESS(IN)	A SUB J	WALL THICK-	DOSE
1	CENTER DOOR	12.000	0.000	20.000	6.28400	2.0000	7.600E-01	3.17407E-00	
2	DOOR 1 LEFT	12.000	37.500	62.500	1.00000	6.0000	4.400E-01	2.11200E-01	
3	DOOR 1 RIGHT	12.000	37.500	62.500	1.00000	6.0000	4.400E-01	2.11200E-01	
4	DOOR 2 LEFT	12.000	87.500	112.500	0.50000	10.0000	2.600E-01	3.21951E-02	
5	DOOR 2 RIGHT	12.000	87.500	112.500	0.50000	10.0000	2.600E-01	3.21951E-02	
6	DOOR 3 LEFT	12.000	137.500	162.500	0.33300	14.0000	1.500E-01	8.29067E-03	
7	DOOR 3 RIGHT	12.000	137.500	162.500	0.33300	14.0000	1.500E-01	8.29067E-03	
8	DOOR 4 LEFT	12.000	187.500	212.500	0.25000	18.0000	8.600E-02	2.68129E-03	
9	DOOR 4 RIGHT	12.000	187.500	212.500	0.25000	18.0000	8.600E-02	2.68129E-03	
10	DOOR 5 LEFT	12.000	237.500	262.500	0.20000	22.0000	5.900E-02	9.98524E-04	
11	DOOR 5 RIGHT	12.000	237.500	262.500	0.20000	22.0000	5.900E-02	9.98524E-04	
12	DOOR 6 LEFT	12.000	287.500	312.500	0.16670	26.0000	2.900E-02	4.07444E-04	
13	DOOR 6 RIGHT	12.000	287.500	312.500	0.16670	26.0000	2.900E-02	4.07444E-04	
14	CENTER YARD - LAWN	3.000	20.000	37.500	6.28400	2.0000	7.600E-01	2.96421E-00	
15	SIDE YARD 1-2 LEFT	3.000	62.500	87.500	0.66660	6.0000	4.400E-01	9.85234E-02	
16	SIDE YARD 1-2 RIGHT	3.000	62.500	87.500	0.66660	6.0000	4.400E-01	9.85234E-02	
17	SIDE YARD 2-3 LEFT	3.000	112.500	137.500	0.40000	10.0000	2.600E-01	2.08575E-02	
18	SIDE YARD 2-3 RIGHT	3.000	112.500	137.500	0.40000	10.0000	2.600E-01	2.08575E-02	
19	SIDE YARD 3-4 LEFT	3.000	162.500	187.500	0.28600	14.0000	1.500E-01	6.13721E-03	
20	SIDE YARD 3-4 RIGHT	3.000	162.500	187.500	0.28600	14.0000	1.500E-01	6.13721E-03	
21	SIDE YARD 4-5 LEFT	3.000	212.500	237.500	0.22200	18.0000	8.600E-02	2.12314E-03	
22	SIDE YARD 4-5 RIGHT	3.000	212.500	237.500	0.22200	18.0000	8.600E-02	2.12314E-03	
23	SIDE YARD 5-6 LEFT	3.000	262.500	287.500	0.18200	22.0000	5.900E-02	8.27744E-04	
24	SIDE YARD 5-6 RIGHT	3.000	262.500	287.500	0.18200	22.0000	5.900E-02	8.27744E-04	
25	BACK YARD CENTER L	3.000	37.500	300.000	0.98400	2.0000	7.600E-01	1.55274E-00	
26	BACK YARD CENTER R	3.000	37.500	300.000	0.98400	2.0000	7.600E-01	1.55274E-00	
27	FRONT YARD CENTER L	3.000	37.500	300.000	0.98400	2.0000	7.600E-01	1.55274E-00	
28	FRONT YARD CENTER R	3.000	37.500	300.000	0.98400	2.0000	7.600E-01	1.55274E-00	
29	BACK YARD A LEFT	3.000	59.600	300.000	0.31000	6.0000	4.400E-01	2.20274E-01	
30	BACK YARD A RIGHT	3.000	59.600	300.000	0.31000	6.0000	4.400E-01	2.20274E-01	
31	FRONT YARD A LEFT	3.000	59.600	300.000	0.31000	6.0000	4.400E-01	2.20274E-01	
32	FRONT YARD A RIGHT	3.000	59.600	300.000	0.31000	6.0000	4.400E-01	2.20274E-01	
33	BACK YARD B LEFT	3.000	110.200	300.000	0.09800	10.0000	2.600E-01	2.55097E-02	
34	BACK YARD B RIGHT	3.000	110.200	300.000	0.09800	10.0000	2.600E-01	2.55097E-02	
35	FRONT YARD C LEFT	3.000	110.200	300.000	0.09800	10.0000	2.600E-01	2.55097E-02	
36	FRONT YARD C RIGHT	3.000	110.200	300.000	0.09800	10.0000	2.600E-01	2.55097E-02	
37	BACK YARD D LEFT	3.000	160.100	300.000	0.05600	14.0000	1.500E-01	5.27401E-03	
38	BACK YARD D RIGHT	3.000	160.100	300.000	0.05600	14.0000	1.500E-01	5.27401E-03	
39	FRONT YARD E LEFT	3.000	160.100	300.000	0.05600	14.0000	1.500E-01	5.27401E-03	
40	FRONT YARD E RIGHT	3.000	160.100	300.000	0.05600	14.0000	1.500E-01	5.27401E-03	
41	BACK YARD F LEFT	3.000	220.200	300.000	0.03800	18.0000	8.600E-02	1.01048E-03	
42	BACK YARD F RIGHT	3.000	220.200	300.000	0.03800	18.0000	8.600E-02	1.01048E-03	
43	FRONT YARD G LEFT	3.000	220.200	300.000	0.03800	18.0000	8.600E-02	1.01048E-03	
44	FRONT YARD G RIGHT	3.000	220.200	300.000	0.03800	18.0000	8.600E-02	1.01048E-03	
45	BACK YARD H LEFT	3.000	275.700	300.000	0.00800	22.0000	5.900E-02	3.37840E-05	
46	BACK YARD H RIGHT	3.000	275.700	300.000	0.00800	22.0000	5.900E-02	3.37840E-05	
47	FRONT YARD I LEFT	3.000	275.700	300.000	0.00800	22.0000	5.900E-02	3.37840E-05	
48	FRONT YARD I RIGHT	3.000	275.700	300.000	0.00800	22.0000	5.900E-02	3.37840E-05	
TOTAL RELATIVE DOSE = 1.4126E 01									
= 55.815 PER CENT OF BACKGROUND RADIATION									

Table 8

RESIDENTIAL AREA WITH ATTENUATION

PROJECT SECURITY PERIOD WITH ATTENUATION

PROJECT SECURITY PERIOD (1/1/67-12/31/67) --- DATA ASSUMED TO BE INFINITE PLANNED
RELATIVE SOURCE COORDINATES --- RESIDENTIAL AREA RELATIVE TO INFINITE PLANNED
2 INCH WOODEN WALLS ROOFS 15 FEBRUARY 1965
LOCATION OF COORDINATE ORIGIN IS CENTER OF CENTER HOUSE 5 FEET ABOVE FLOOR

PARAMETERS ---
D SQ. INFINITY = 4.800E-04 NUMBER OF AREAS = 48
INTEGRATIONS VIA ACROSS-SECTION VARIABLE INCREMENT METHOD

AREA NO.	AREA IDENTIFICATION	HEIGHT (FT)	AREA (SQ. FT)	AREA (SQ. FT)	HEIGHT (FT)	HEIGHT (FT)	PERCENTAGE OF D.F.
1	CENTER ROOF	12.000	0.000	25.000	0.000	0.000	0.000
2	ROOF 1 LEFT	12.000	37.500	0.000	0.000	0.000	0.000
3	ROOF 1 RIGHT	12.000	37.500	0.000	0.000	0.000	0.000
4	ROOF 2 LEFT	12.000	87.500	14.000	0.000	0.000	0.000
5	ROOF 2 RIGHT	12.000	87.500	14.000	0.000	0.000	0.000
6	ROOF 3 LEFT	12.000	137.500	18.000	0.000	0.000	0.000
7	ROOF 3 RIGHT	12.000	137.500	18.000	0.000	0.000	0.000
8	ROOF 4 LEFT	12.000	187.500	24.000	0.000	0.000	0.000
9	ROOF 4 RIGHT	12.000	187.500	24.000	0.000	0.000	0.000
10	ROOF 5 LEFT	12.000	237.500	28.000	0.000	0.000	0.000
11	ROOF 5 RIGHT	12.000	237.500	28.000	0.000	0.000	0.000
12	ROOF 6 LEFT	12.000	287.500	32.000	0.000	0.000	0.000
13	ROOF 6 RIGHT	12.000	287.500	32.000	0.000	0.000	0.000
14	CENTER YARD - LAWN	3.000	25.000	0.000	0.000	0.000	0.000
15	SIDE YARD 1-2 LEFT	3.000	62.500	0.000	0.000	0.000	0.000
16	SIDE YARD 1-2 RIGHT	3.000	62.500	0.000	0.000	0.000	0.000
17	SIDE YARD 2-3 LEFT	3.000	112.500	0.000	0.000	0.000	0.000
18	SIDE YARD 2-3 RIGHT	3.000	112.500	0.000	0.000	0.000	0.000
19	SIDE YARD 3-4 LEFT	3.000	162.500	0.000	0.000	0.000	0.000
20	SIDE YARD 3-4 RIGHT	3.000	162.500	0.000	0.000	0.000	0.000
21	SIDE YARD 4-5 LEFT	3.000	212.500	0.000	0.000	0.000	0.000
22	SIDE YARD 4-5 RIGHT	3.000	212.500	0.000	0.000	0.000	0.000
23	SIDE YARD 5-6 LEFT	3.000	262.500	0.000	0.000	0.000	0.000
24	SIDE YARD 5-6 RIGHT	3.000	262.500	0.000	0.000	0.000	0.000
25	BACK YARD CENTER L	3.000	37.500	300.000	0.000	0.000	0.000
26	BACK YARD CENTER R	3.000	37.500	300.000	0.000	0.000	0.000
27	FRONT YARD CENTER L	3.000	37.500	300.000	0.000	0.000	0.000
28	FRONT YARD CENTER R	3.000	37.500	300.000	0.000	0.000	0.000
29	BACK YARD 5 LEFT	3.000	59.600	300.000	0.000	0.000	0.000
30	BACK YARD 5 RIGHT	3.000	59.600	300.000	0.000	0.000	0.000
31	FRONT YARD 5 LEFT	3.000	59.600	300.000	0.000	0.000	0.000
32	FRONT YARD 5 RIGHT	3.000	59.600	300.000	0.000	0.000	0.000
33	BACK YARD 6 LEFT	3.000	110.200	300.000	0.000	0.000	0.000
34	BACK YARD 6 RIGHT	3.000	110.200	300.000	0.000	0.000	0.000
35	FRONT YARD 6 LEFT	3.000	110.200	300.000	0.000	0.000	0.000
36	FRONT YARD 6 RIGHT	3.000	110.200	300.000	0.000	0.000	0.000
37	BACK YARD 7 LEFT	3.000	160.100	300.000	0.000	0.000	0.000
38	BACK YARD 7 RIGHT	3.000	160.100	300.000	0.000	0.000	0.000
39	FRONT YARD 7 LEFT	3.000	160.100	300.000	0.000	0.000	0.000
40	FRONT YARD 7 RIGHT	3.000	160.100	300.000	0.000	0.000	0.000
41	BACK YARD 8 LEFT	3.000	220.200	300.000	0.000	0.000	0.000
42	BACK YARD 8 RIGHT	3.000	220.200	300.000	0.000	0.000	0.000
43	FRONT YARD 8 LEFT	3.000	220.200	300.000	0.000	0.000	0.000
44	FRONT YARD 8 RIGHT	3.000	220.200	300.000	0.000	0.000	0.000
45	BACK YARD 9 LEFT	3.000	275.700	300.000	0.000	0.000	0.000
46	BACK YARD 9 RIGHT	3.000	275.700	300.000	0.000	0.000	0.000
47	FRONT YARD 9 LEFT	3.000	275.700	300.000	0.000	0.000	0.000
48	FRONT YARD 9 RIGHT	3.000	275.700	300.000	0.000	0.000	0.000

TOTAL RELATIVE DOSE = 4.4200E-04
= 50.245 PER CENT OF BACKGROUND RADIATION

Table 9

SHOPPING PLAZA WITH FIXED ATTENUATION

PROJECT RADIAP (W/A=E12-11C) --- J. RINALDO, DEPT. 4707

RELATIVE DOSE RATE COMPUTATIONS --- DOSE RATE CALCULATIONS FOR SHOPPING PLAZA FIXED ATTENUATION

RADIAP PROJECT E12-11C 22 JAN 63 J. RINALDO CONCRETE STRUCTURE

LOCATION OF COORDINATE ORIGIN IS CENTER OF CENTER STORE

PARAMETERS ---

D SUB INFINITY = 2.5300E 03

NUMBER OF AREAS = 37

AREA NO.	AREA IDENTIFICATION	H (FT)	R ONE (FT)	P TWO (FT)	THETA (RAD)	NESS (IN)	A SUR J	DOSE
1	CENTER ROOFTOP	12.000	0.	56.419	6.28369	12.0000	1.2205E-03	1.2205E-03
2	ROOFTOP FOR HOUSE 1 RIGHT	12.000	56.419	149.500	1.00500	24.0000	1.4905E-06	1.4905E-06
3	ROOFTOP FOR HOUSE 1 LEFT	12.000	56.419	149.500	1.00500	24.0000	1.4905E-06	1.4905E-06
4	ROOFTOP FOR HOUSE 2 RIGHT	12.000	149.500	249.500	0.50130	36.0000	1.8005E-09	4.60290E-10
5	ROOFTOP FOR HOUSE 2 LEFT	12.000	149.500	249.500	0.50130	36.0000	1.8005E-09	4.60290E-10
6	ROOFTOP FOR HOUSE 3 RIGHT	12.000	249.500	349.500	0.33390	48.0000	2.2105E-12	2.48290E-13
7	ROOFTOP FOR HOUSE 3 LEFT	12.000	249.500	349.500	0.33390	48.0000	2.2105E-12	2.48290E-13
8	ROOFTOP FOR HOUSE 4 RIGHT	12.000	349.500	449.500	0.25030	60.0000	2.6905E-15	1.69240E-16
9	ROOFTOP FOR HOUSE 4 LEFT	12.000	349.500	449.500	0.25030	60.0000	2.6905E-15	1.69240E-16
10	ROOFTOP FOR HOUSE 5 RIGHT	12.000	449.500	549.500	0.20020	72.0000	3.2505E-18	1.30621E-19
11	ROOFTOP FOR HOUSE 5 LEFT	12.000	449.500	549.500	0.20020	72.0000	3.2505E-18	1.30621E-19
12	ROOFTOP FOR HOUSE 6 RIGHT	12.000	549.500	600.000	0.16680	90.0000	3.9705E-21	5.81934E-23
13	ROOFTOP FOR HOUSE 6 LEFT	12.000	549.500	600.000	0.16680	90.0000	3.9705E-21	5.81934E-23
14	BACK LOT 1 RIGHT	3.000	56.419	600.000	0.79050	12.0000	1.2205E-03	2.27845E-04
15	BACK LOT 1 LEFT	3.000	56.419	600.000	0.79050	12.0000	1.2205E-03	2.27845E-04
16	BACK LOT 2 RIGHT	3.000	95.987	600.000	0.46300	24.0000	1.4905E-06	1.26401E-06
17	BACK LOT 2 LEFT	3.000	95.987	600.000	0.46300	24.0000	1.4905E-06	1.26401E-06
18	BACK LOT 3 RIGHT	3.000	197.472	600.000	0.12200	36.0000	1.8005E-09	2.44026E-10
19	BACK LOT 3 LEFT	3.000	197.472	600.000	0.12200	36.0000	1.8005E-09	2.44026E-10
20	BACK LOT 4 RIGHT	3.000	300.842	600.000	0.03600	48.0000	2.2505E-12	8.69797E-14
21	BACK LOT 4 LEFT	3.000	300.842	600.000	0.03600	48.0000	2.2505E-12	8.69797E-14
22	BACK LOT 5 RIGHT	3.000	404.204	600.000	0.03000	60.0000	2.6905E-15	3.18741E-17
23	BACK LOT 5 LEFT	3.000	404.204	600.000	0.03000	60.0000	2.6905E-15	3.18741E-17
24	BACK LOT 6 RIGHT	3.000	506.072	600.000	0.02000	72.0000	3.2505E-18	1.10660E-20
25	BACK LOT 6 LEFT	3.000	506.072	600.000	0.02000	72.0000	3.2505E-18	1.10660E-20
26	FRONT LOT 1 RIGHT	3.000	56.419	600.000	0.79050	0.	1.8005E-09	1.96774E-09
27	FRONT LOT 1 LEFT	3.000	56.419	600.000	0.79050	0.	1.8005E-09	1.96774E-09
28	FRONT LOT 2 RIGHT	3.000	95.987	600.000	0.46300	12.0000	1.2205E-03	1.03455E-03
29	FRONT LOT 2 LEFT	3.000	95.987	600.000	0.46300	12.0000	1.2205E-03	1.03455E-03
30	FRONT LOT 3 RIGHT	3.000	197.472	600.000	0.12200	24.0000	1.4905E-06	2.01999E-07
31	FRONT LOT 3 LEFT	3.000	197.472	600.000	0.12200	24.0000	1.4905E-06	2.01999E-07
32	FRONT LOT 4 RIGHT	3.000	300.842	600.000	0.03600	36.0000	1.8005E-09	6.95903E-11
33	FRONT LOT 4 LEFT	3.000	300.842	600.000	0.03600	36.0000	1.8005E-09	6.95903E-11
34	FRONT LOT 5 RIGHT	3.000	404.204	600.000	0.03000	48.0000	2.2105E-12	2.61825E-14
35	FRONT LOT 5 LEFT	3.000	404.204	600.000	0.03000	48.0000	2.2105E-12	2.61825E-14
36	FRONT LOT 6 RIGHT	3.000	506.072	600.000	0.02000	60.0000	2.6905E-15	8.15921E-17
37	FRONT LOT 6 LEFT	3.000	506.072	600.000	0.02000	60.0000	2.6905E-15	8.15921E-17

TOTAL RELATIVE DOSE = 3.7541E 00

= 14.833 PER CENT OF BACKGROUND RADIATION

Table 10

SHOPPING PLAZA WITH ATTENUATION

SECTOR GEOMETRY METHOD WITH ATTENUATION

PROJECT RADIOS (M/FEET/INCH) --- J.S. RALLO, SEPT. 4, 1977

RELATIVE DOSE RATE COMPUTATIONS --- DOSE RATE CALCULATIONS FOR SHOPPING PLAZA (WITH ATTENUATION)

RADTAP PROJECT E12-110 22 JAN 65 J. RALLO CONCRETE STRUCTURE

LOCATION OF COORDINATE ORIGIN IS CENTER OF CENTER STORE

PARAMETERS ---
 2 SUR INFINITY = 2.500E 01 NUMBER OF AREAS = 37
 INTEGRATIONS VIA ADAMS-MOULTON VARIABLE INCREMENT METHOD

AREA NO.	AREA IDENTIFICATION	H (FT)	R ONE (FT)	R TWO (FT)	THETA (RAD)	DOSE	PERCENTAGE OF 5 IN
1	CENTER ROOFTOP	12.000	0.	56.419	0.28286	4.57613E-01	1.0000
2	ROOFTOP FOR HOUSE 1 RIGHT	12.000	56.419	135.500	1.00000	4.85693E-03	0.0001
3	ROOFTOP FOR HOUSE 1 LEFT	12.000	56.419	135.500	1.00000	4.85693E-03	0.0001
4	ROOFTOP FOR HOUSE 2 RIGHT	12.000	147.500	245.500	0.950130	9.86253E-13	0.0000
5	ROOFTOP FOR HOUSE 2 LEFT	12.000	147.500	245.500	0.950130	9.86253E-13	0.0000
6	ROOFTOP FOR HOUSE 3 RIGHT	12.000	249.500	345.500	0.83390	2.95537E-14	0.0000
7	ROOFTOP FOR HOUSE 3 LEFT	12.000	249.500	345.500	0.83390	2.95537E-14	0.0000
8	ROOFTOP FOR HOUSE 4 RIGHT	12.000	349.500	445.500	0.63030	1.42497E-15	0.0000
9	ROOFTOP FOR HOUSE 4 LEFT	12.000	349.500	445.500	0.63030	1.42497E-15	0.0000
10	ROOFTOP FOR HOUSE 5 RIGHT	12.000	449.500	545.500	0.50020	0.	0.
11	ROOFTOP FOR HOUSE 5 LEFT	12.000	449.500	545.500	0.50020	0.	0.
12	ROOFTOP FOR HOUSE 6 RIGHT	12.000	549.500	600.000	0.16650	0.	0.
13	ROOFTOP FOR HOUSE 6 LEFT	12.000	549.500	600.000	0.16650	0.	0.
14	BACK LOT 1 RIGHT	3.000	56.419	600.000	0.79050	0.33118E-03	0.0003
15	BACK LOT 1 LEFT	3.000	56.419	600.000	0.79050	0.33118E-03	0.0003
16	BACK LOT 2 RIGHT	3.000	95.587	600.000	0.49300	2.82592E-04	0.0000
17	BACK LOT 2 LEFT	3.000	95.587	600.000	0.49300	2.82592E-04	0.0000
18	BACK LOT 3 RIGHT	3.000	197.472	600.000	0.12400	3.59113E-12	0.0000
19	BACK LOT 3 LEFT	3.000	197.472	600.000	0.12400	3.59113E-12	0.0000
20	BACK LOT 4 RIGHT	3.000	300.342	600.000	0.03600	1.02125E-13	0.0000
21	BACK LOT 4 LEFT	3.000	300.342	600.000	0.03600	1.02125E-13	0.0000
22	BACK LOT 5 RIGHT	3.000	404.204	600.000	0.03000	2.86151E-12	0.0000
23	BACK LOT 5 LEFT	3.000	404.204	600.000	0.03000	2.86151E-12	0.0000
24	BACK LOT 6 RIGHT	3.000	506.072	600.000	0.02000	7.84057E-23	0.0000
25	BACK LOT 6 LEFT	3.000	506.072	600.000	0.02000	7.84057E-23	0.0000
26	FRONT LOT 1 RIGHT	3.000	56.419	600.000	0.79050	5.58616E-01	3.7664
27	FRONT LOT 1 LEFT	3.000	56.419	600.000	0.79050	5.58616E-01	3.7664
28	FRONT LOT 2 RIGHT	3.000	95.587	600.000	0.49300	4.31274E-03	0.0002
29	FRONT LOT 2 LEFT	3.000	95.587	600.000	0.49300	4.31274E-03	0.0002
30	FRONT LOT 3 RIGHT	3.000	197.472	600.000	0.12400	4.76335E-04	0.0000
31	FRONT LOT 3 LEFT	3.000	197.472	600.000	0.12400	4.76335E-04	0.0000
32	FRONT LOT 4 RIGHT	3.000	300.342	600.000	0.03600	1.05447E-12	0.0000
33	FRONT LOT 4 LEFT	3.000	300.342	600.000	0.03600	1.05447E-12	0.0000
34	FRONT LOT 5 RIGHT	3.000	404.204	600.000	0.03000	2.91333E-13	0.0000
35	FRONT LOT 5 LEFT	3.000	404.204	600.000	0.03000	2.91333E-13	0.0000
36	FRONT LOT 6 RIGHT	3.000	506.072	600.000	0.02000	7.82103E-23	0.0000
37	FRONT LOT 6 LEFT	3.000	506.072	600.000	0.02000	7.82103E-23	0.0000

TOTAL RELATIVE DOSE = 2.3756E 00

= 5.366 PER CENT OF BACKGROUND RADIATION

TABLE II

Relative Dose Rate Along Center of Street

Origin	Contribution No Decontamination	Contribution 50% Remnant
A	83.4 %	49.4 %
B	87.6 %	53.6 %
C	90.0 %	56.0 %
D	83.4 %	49.4 %
E	81.7 %	47.7 %

Table 12
TYPICAL DATA RUN FOR CITY COMPLEX
RECTANGULAR GEOMETRY METHOD WITH FLOATING ORIGIN AND FIXED ATTENUATION

PROJECT RADTAP (M/A=E12-110) --- J.RINALDO, DEPT.470

RELATIVE DOSAGE COMPUTATIONS --- 161 AREAS --- CITY COMPLEX TARGET AREA ---

INTEGRATIONS ON X VIA SIMPSON RULE
Y VIA ADAMS-MOULTON VARIABLE INCREMENT METHOD

PARAMETERS --- D SUB INFINITY = 2.5309E 01
NUMBER OF AREAS = 161

SAVED INPUT DATA APPEARS IN FILE 1 OF BINARY TAPE 5

ATTENUATION COEFFICIENTS

CODE	MEDIUM	ALT.	K	X(K)	Y(K)	K	X(K)	Y(K)
ER	EFFECTIVE AIR	96.0	1	0.	600.0	3	90.0	500.0
AR	AIR		2	0.	500.0	4	90.0	600.0
CN	CONCRETE		1	90.0	600.0	3	100.0	500.0
BR	BRICK		2	90.0	500.0	4	100.0	600.0
ST	STONE		1	100.0	600.0	3	140.0	500.0
WD	WOOD		2	100.0	500.0	4	140.0	600.0
			1	140.0	600.0	3	150.0	500.0
			2	140.0	500.0	4	150.0	600.0
			1	150.0	600.0	3	210.0	500.0
			2	150.0	500.0	4	210.0	600.0
			1	210.0	600.0	3	220.0	500.0
			2	210.0	500.0	4	220.0	600.0
			1	220.0	600.0	3	270.0	500.0
			2	220.0	500.0	4	270.0	600.0
			1	270.0	600.0	3	280.0	500.0
			2	270.0	500.0	4	280.0	600.0
			1	280.0	600.0	3	320.0	500.0
			2	280.0	500.0	4	320.0	600.0
			1	320.0	600.0	3	330.0	500.0
			2	320.0	500.0	4	330.0	600.0
			1	330.0	600.0	3	360.0	500.0
			2	330.0	500.0	4	360.0	600.0
			1	360.0	600.0	3	370.0	500.0

LIST OF AREAS PROCESSED

AREA	IDENTIFICATION	ALT.	K	X(K)	Y(K)	K	X(K)	Y(K)
1	BUILDING 1 8 STORY BRICK	96.0	1	0.	600.0	3	90.0	500.0
2	ALLEY BETWEEN BUILDINGS 1 AND 3	0.	1	0.	500.0	4	90.0	600.0
3	BUILDING 3 6 STORY BRICK	72.0	2	90.0	600.0	4	100.0	500.0
4	ALLEY BETWEEN BUILDING 3 AND 5	0.	1	100.0	600.0	3	140.0	500.0
5	BUILDING 5 7 STORY CONCRETE	84.0	2	100.0	500.0	4	140.0	600.0
6	ALLEY BETWEEN BUILDING 5 AND 7	0.	1	140.0	600.0	3	150.0	500.0
7	BUILDING 7 12 STORY CONCRETE	144.0	2	140.0	500.0	4	150.0	600.0
8	ALLEY BETWEEN BUILDINGS 7 AND 9	0.	1	150.0	600.0	3	210.0	500.0
9	BUILDING 9 4 STORY BRICK	48.0	2	150.0	500.0	4	210.0	600.0
10	ALLEY BETWEEN BUILDINGS 9 AND 11	0.	1	210.0	600.0	3	220.0	500.0
11	BUILDING 11 1 STORY BRICK	12.0	2	210.0	500.0	4	220.0	600.0
12	ALLEY BETWEEN BUILDINGS 11 AND 13	0.	1	220.0	600.0	3	270.0	500.0

Table 12 (Cont.)
BUILDING 13 5 STORY CONCRETE

13	BUILDING 13 5 STORY CONCRETE	36.0	2	360.0	500.0	4	370.0	600.0
14	ALLEY BETWEEN BUILDINGS 13 AND 15	0.	2	370.0	600.0	3	420.0	500.0
15	BUILDING 15 10 STORY STONE	120.0	2	420.0	500.0	3	430.0	500.0
16	STREET AREA BEHIND BUILDING 27	0.	1	0.	500.0	3	500.0	500.0
17	STREET AREA BEHIND ALLEY 28	0.	2	3.	450.0	4	60.0	500.0
18	STREET AREA BEHIND BUILDING 29	0.	2	80.0	450.0	4	90.0	500.0
19	STREET AREA BEHIND PARKING LOT 30	0.	2	90.0	450.0	4	140.0	500.0
20	STREET AREA BEHIND BUILDING 31	0.	2	140.0	450.0	4	240.0	500.0
21	STREET AREA BEHIND ALLEY 32	0.	2	240.0	450.0	4	300.0	500.0
22	STREET AREA BEHIND BUILDING 33	0.	2	300.0	450.0	4	310.0	500.0
23	STREET AREA BEHIND ALLEY 34	0.	2	310.0	450.0	4	390.0	450.0
24	STREET AREA BEHIND BUILDING 35	0.	2	390.0	450.0	4	400.0	450.0
25	STREET AREA BEHIND ALLEY 36	0.	2	400.0	450.0	4	440.0	450.0
26	STREET AREA BEHIND BUILDING 37	0.	2	440.0	450.0	4	450.0	500.0
27	BUILDING 27 7 STORY BRICK	84.0	2	450.0	450.0	4	500.0	500.0
28	ALLEY BETWEEN BUILDINGS 27 AND 29	0.	2	0.	350.0	4	80.0	420.0
29	BUILDING 29 9 STORY CONCRETE	108.0	2	80.0	450.0	3	90.0	350.0
30	PARKING LOT 30	0.	2	90.0	450.0	3	140.0	350.0
31	BUILDING 31 1 STORY BRICK	12.0	2	140.0	350.0	4	240.0	450.0
32	ALLEY BETWEEN BUILDINGS 31 AND 33	0.	2	240.0	350.0	4	300.0	350.0
33	BUILDING 33 2 STORY BRICK	24.0	2	300.0	350.0	4	310.0	350.0
34	ALLEY BETWEEN BUILDINGS 33 AND 35	0.	2	310.0	350.0	4	390.0	450.0
35	BUILDING 35 8 STORY BRICK	96.0	2	390.0	350.0	4	400.0	450.0
36	ALLEY BETWEEN BUILDINGS 35 AND 37	0.	2	400.0	350.0	4	440.0	450.0
37	BUILDING 37 6 STORY BRICK	72.0	2	440.0	350.0	4	450.0	450.0
38	BUILDING 38 8 STORY STONE	96.0	2	450.0	350.0	4	500.0	450.0
39	ALLEY BETWEEN BUILDINGS 38 AND 40	0.	2	0.	250.0	3	60.0	150.0
40	BUILDING 40 10 STORY CONCRETE	120.0	2	60.0	250.0	3	70.0	150.0
41	ALLEY BETWEEN BUILDINGS 40 AND 42	0.	2	70.0	250.0	4	130.0	150.0
42	BUILDING 42 3 STORY STONE	36.0	2	130.0	250.0	4	140.0	250.0
43	ALLEY BETWEEN BUILDINGS 42 AND 44	0.	2	140.0	250.0	3	230.0	150.0
44	BUILDING 44 5 STORY BRICK	60.0	2	230.0	250.0	4	240.0	250.0
45	ALLEY BETWEEN BUILDINGS 44 AND 46	0.	2	240.0	250.0	4	250.0	250.0

Table 12 (Cont.)
BUILDING 46 1 STORY BRICK
GASOLINE STATION

46	BUILDING 46 1 STORY BRICK	12.0	2	290.0	150.0	4	300.0	250.0
47	GASOLINE STATION	0.0	2	300.0	250.0	5	350.0	150.0
48	GARAGE IN GAS STATION 1 STORY BRICK	12.0	2	350.0	250.0	4	300.0	250.0
49	STREET AREA BEHIND BUILDING 38	0.0	2	350.0	150.0	5	410.0	200.0
50	STREET AREA BEHIND ALLEY 39	0.0	2	500.0	150.0	5	410.0	200.0
51	STREET AREA BEHIND BUILDING 40	0.0	2	360.0	200.0	4	410.0	200.0
52	STREET AREA BEHIND ALLEY 41	0.0	2	0.0	150.0	3	60.0	100.0
53	STREET AREA BEHIND BUILDING 42	0.0	2	0.0	100.0	4	60.0	150.0
54	STREET AREA BEHIND ALLEY 43	0.0	2	60.0	150.0	3	70.0	100.0
55	STREET AREA BEHIND BUILDING 44	0.0	2	70.0	100.0	4	70.0	150.0
56	STREET AREA BEHIND ALLEY 45	0.0	2	130.0	100.0	4	140.0	100.0
57	STREET AREA BEHIND BUILDING 46	0.0	2	130.0	100.0	4	140.0	100.0
58	STREET AREA BEHIND GASOLINE STATION	0.0	2	140.0	150.0	5	230.0	150.0
59	PARKING LOT 59	0.0	2	140.0	100.0	4	230.0	150.0
60	BUILDING 60 1 STORY BRICK	12.0	2	230.0	150.0	3	240.0	100.0
61	ALLEY BETWEEN BUILDINGS 60 AND 62	0.0	2	230.0	100.0	4	240.0	150.0
62	BUILDING 62 3 STORY CONCRETE	36.0	2	240.0	100.0	4	290.0	150.0
63	ALLEY BETWEEN BUILDINGS 62 AND 64	0.0	2	280.0	150.0	5	300.0	100.0
64	BUILDING 64 5 STORY CONCRETE	60.0	2	290.0	100.0	4	300.0	150.0
65	ALLEY BETWEEN BUILDINGS 64 AND 66	0.0	2	300.0	100.0	4	350.0	150.0
66	BUILDING 66 2 STORY STONE	24.0	2	350.0	100.0	4	500.0	150.0
67	ALLEY BETWEEN BUILDINGS 66 AND 68	0.0	2	0.0	100.0	4	150.0	100.0
68	BUILDING 68 2 STORY STONE	24.0	2	150.0	100.0	5	250.0	100.0
69	PARKING RAMP 4 STORY CONCRETE	48.0	2	250.0	100.0	4	260.0	100.0
70	ALLEY BETWEEN RAMP AND BUILDING 71	0.0	2	280.0	100.0	5	320.0	100.0
71	BUILDING 71 9 STORY STONE	108.0	2	320.0	100.0	4	390.0	100.0
72	ALLEY BETWEEN BUILDINGS 71 AND 73	0.0	2	320.0	100.0	5	420.0	100.0
73	BUILDING 73 10 STORY STONE	120.0	2	390.0	100.0	4	420.0	100.0
74	ALLEY BETWEEN BUILDINGS 73 AND 75	0.0	2	420.0	100.0	5	430.0	100.0
75	BUILDING 75 6 STORY BRICK	72.0	2	420.0	100.0	5	500.0	100.0
76	STREET AREA BEHIND BUILDING 93	0.0	2	430.0	100.0	4	500.0	100.0
77	STREET AREA BEHIND ALLEY 94	0.0	2	430.0	100.0	5	500.0	100.0
78	STREET AREA BEHIND BUILDING 95	0.0	2	430.0	100.0	5	500.0	100.0
79	STREET AREA BEHIND BUILDING 96	0.0	2	430.0	100.0	5	500.0	100.0
80	STREET AREA BEHIND BUILDING 97	0.0	2	430.0	100.0	5	500.0	100.0
81	STREET AREA BEHIND BUILDING 98	0.0	2	430.0	100.0	5	500.0	100.0
82	STREET AREA BEHIND BUILDING 99	0.0	2	430.0	100.0	5	500.0	100.0
83	STREET AREA BEHIND BUILDING 100	0.0	2	430.0	100.0	5	500.0	100.0
84	STREET AREA BEHIND BUILDING 101	0.0	2	430.0	100.0	5	500.0	100.0
85	STREET AREA BEHIND BUILDING 102	0.0	2	430.0	100.0	5	500.0	100.0
86	STREET AREA BEHIND BUILDING 103	0.0	2	430.0	100.0	5	500.0	100.0
87	STREET AREA BEHIND BUILDING 104	0.0	2	430.0	100.0	5	500.0	100.0
88	STREET AREA BEHIND BUILDING 105	0.0	2	430.0	100.0	5	500.0	100.0
89	STREET AREA BEHIND BUILDING 106	0.0	2	430.0	100.0	5	500.0	100.0
90	STREET AREA BEHIND BUILDING 107	0.0	2	430.0	100.0	5	500.0	100.0
91	STREET AREA BEHIND BUILDING 108	0.0	2	430.0	100.0	5	500.0	100.0
92	STREET AREA BEHIND BUILDING 109	0.0	2	430.0	100.0	5	500.0	100.0
93	STREET AREA BEHIND BUILDING 110	0.0	2	430.0	100.0	5	500.0	100.0
94	STREET AREA BEHIND BUILDING 111	0.0	2	430.0	100.0	5	500.0	100.0
95	STREET AREA BEHIND BUILDING 112	0.0	2	430.0	100.0	5	500.0	100.0
96	STREET AREA BEHIND BUILDING 113	0.0	2	430.0	100.0	5	500.0	100.0
97	STREET AREA BEHIND BUILDING 114	0.0	2	430.0	100.0	5	500.0	100.0
98	STREET AREA BEHIND BUILDING 115	0.0	2	430.0	100.0	5	500.0	100.0
99	STREET AREA BEHIND BUILDING 116	0.0	2	430.0	100.0	5	500.0	100.0
100	STREET AREA BEHIND BUILDING 117	0.0	2	430.0	100.0	5	500.0	100.0

Table 12 (Cont.)

78	STREET AREA BEHIND BUILDING 95	0.	1	650.0	500.0	3	700.0	450.0
79	STREET AREA BEHIND ALLEY 96	0.	2	700.0	450.0	4	700.0	450.0
80	STREET AREA BEHIND BUILDING 97	0.	2	700.0	450.0	3	710.0	500.0
81	STREET AREA BEHIND ALLEY 98	0.	2	710.0	500.0	3	760.0	500.0
82	STREET AREA BEHIND BUILDING 99	0.	2	760.0	450.0	3	770.0	450.0
83	STREET AREA BEHIND ALLEY 100	0.	2	770.0	500.0	3	830.0	500.0
84	STREET AREA BEHIND BUILDING 101	0.	2	830.0	500.0	3	840.0	500.0
85	STREET AREA BEHIND ALLEY 102	0.	2	840.0	450.0	4	870.0	500.0
86	STREET AREA BEHIND BUILDING 103	0.	2	870.0	450.0	4	880.0	500.0
87	STREET AREA BEHIND ALLEY 104	0.	2	880.0	500.0	3	930.0	500.0
88	STREET AREA BEHIND BUILDING 105	0.	2	930.0	450.0	4	940.0	500.0
89	STREET AREA BEHIND ALLEY 106	0.	2	940.0	500.0	3	1010.0	500.0
90	STREET AREA BEHIND BUILDING 107	0.	2	1010.0	500.0	3	1020.0	500.0
91	STREET AREA BEHIND ALLEY 108	0.	2	1020.0	450.0	4	1040.0	500.0
92	STREET AREA BEHIND BUILDING 109	0.	2	1040.0	500.0	3	1050.0	500.0
93	BUILDING 93 12 STORY CONCRETE	144.0	2	1050.0	500.0	3	1100.0	450.0
94	ALLEY BETWEEN BUILDINGS 93 AND 95	0.	2	600.0	450.0	4	640.0	450.0
95	BUILDING 95 12 STORY CONCRETE	144.0	2	640.0	450.0	3	650.0	350.0
96	ALLEY BETWEEN BUILDINGS 95 AND 97	0.	2	650.0	350.0	4	700.0	450.0
97	BUILDING 97 6 STORY BRICK	96.0	2	700.0	350.0	4	710.0	450.0
98	ALLEY BETWEEN BUILDINGS 97 AND 99	0.	2	710.0	350.0	4	760.0	450.0
99	BUILDING 99 7 STORY BRICK	64.0	2	760.0	450.0	3	770.0	350.0
100	ALLEY BETWEEN BUILDINGS 99 AND 101	0.	2	770.0	450.0	3	830.0	450.0
101	BUILDING 101 15 STORY CONCRETE	180.0	2	830.0	350.0	4	840.0	450.0
102	ALLEY BETWEEN BUILDINGS 101 AND 103	0.	2	840.0	450.0	3	870.0	350.0
103	BUILDING 103 10 STORY CONCRETE	120.0	2	870.0	350.0	4	880.0	450.0
104	ALLEY BETWEEN BUILDINGS 103 AND 105	0.	2	880.0	350.0	4	930.0	450.0
105	BUILDING 105 9 STORY BRICK	108.0	2	930.0	350.0	4	940.0	450.0
106	ALLEY BETWEEN BUILDINGS 105 AND 107	0.	2	940.0	350.0	3	1010.0	450.0
107	BUILDING 107 7 STORY BRICK	84.0	2	1010.0	350.0	4	1020.0	450.0
108	ALLEY BETWEEN BUILDINGS 107 AND 109	0.	2	1020.0	450.0	3	1040.0	450.0
109	BUILDING 109 10 STORY CONCRETE	120.0	2	1040.0	350.0	4	1050.0	450.0
110	BUILDING 110 5 STORY STONE	60.0	2	1050.0	350.0	3	1100.0	450.0
			2	600.0	150.0	4	700.0	450.0

Table 12 (Cont.)

111	ALLEY BETWEEN BUILDINGS 110 AND 112	0.	1	700.0	250.0	3	710.0	150.0
112	BUILDING 112 3 STORY WOOD	36.0	2	700.0	150.0	4	710.0	250.0
113	ALLEY BETWEEN BUILDINGS 112 AND 114	0.	1	710.0	250.0	3	760.0	150.0
114	BUILDING 114 9 STORY CONCRETE	108.0	2	760.0	250.0	4	770.0	150.0
115	ALLEY BETWEEN BUILDINGS 114 AND 116	0.	2	760.0	250.0	3	860.0	150.0
116	BUILDING 116 7 STORY CONCRETE	84.0	2	860.0	150.0	4	870.0	250.0
117	ALLEY BETWEEN BUILDINGS 116 AND 118	0.	1	870.0	250.0	3	950.0	150.0
118	BUILDING 118 6 STORY BRICK	72.0	2	950.0	250.0	4	960.0	250.0
119	ALLEY BETWEEN BUILDINGS 118 AND 120	0.	1	960.0	250.0	3	990.0	150.0
120	BUILDING 120 1 STORY BRICK	12.0	2	990.0	250.0	4	1000.0	250.0
121	STREET AREA BEHIND BUILDING 110	0.	2	1000.0	150.0	4	1100.0	250.0
122	STREET AREA BEHIND ALLEY 111	0.	2	600.0	100.0	4	700.0	100.0
123	STREET AREA BEHIND BUILDING 112	0.	2	700.0	150.0	4	710.0	100.0
124	STREET AREA BEHIND ALLEY 113	0.	2	710.0	100.0	4	760.0	150.0
125	STREET AREA BEHIND BUILDING 114	0.	2	760.0	100.0	4	770.0	150.0
126	STREET AREA BEHIND ALLEY 115	0.	1	770.0	150.0	3	860.0	100.0
127	STREET AREA BEHIND BUILDING 116	0.	2	860.0	100.0	4	870.0	150.0
128	STREET AREA BEHIND ALLEY 117	0.	2	870.0	100.0	4	950.0	150.0
129	STREET AREA BEHIND BUILDING 118	0.	2	950.0	100.0	4	960.0	150.0
130	STREET AREA BEHIND ALLEY 119	0.	2	960.0	100.0	4	990.0	150.0
131	STREET AREA BEHIND BUILDING 120	0.	2	990.0	100.0	4	1000.0	150.0
132	BUILDING 132 6 STORY BRICK	72.0	1	1000.0	100.0	3	1100.0	100.0
133	ALLEY BETWEEN BUILDINGS 132 AND 134	0.	2	1000.0	100.0	3	1100.0	150.0
134	BUILDING 134 4 STORY BRICK	48.0	2	600.0	0.	4	680.0	100.0
135	ALLEY BETWEEN BUILDINGS 134 AND 136	0.	2	680.0	0.	4	690.0	100.0
136	BUILDING 136 3 STORY BRICK	36.0	2	690.0	100.0	3	760.0	0.
137	ALLEY BETWEEN BUILDINGS 136 AND 138	0.	2	760.0	0.	4	770.0	0.
138	BUILDING 138 9 STORY BRICK	108.0	2	770.0	100.0	3	840.0	0.
139	ALLEY BETWEEN BUILDINGS 138 AND 140	0.	2	840.0	0.	4	850.0	100.0
140	BUILDING 140 8 STORY BRICK	96.0	2	850.0	100.0	3	900.0	0.
141	ALLEY BETWEEN BUILDINGS 140 AND 142	0.	2	900.0	0.	4	900.0	100.0
142	BUILDING 142 6 STORY BRICK	72.0	2	950.0	0.	4	1000.0	100.0
143	ALLEY BETWEEN BUILDINGS 142 AND 144	0.	2	1000.0	0.	4	1040.0	0.
			2	1040.0	100.0	4	1050.0	100.0

Table 12 (Cont.)
BUILDING 144 5 STORY BRICK

144	STREET AREA	0.	1	1050.0	100.0	3	1100.0	0.
145	STREET AREA	0.	2	1050.0	0.	4	1100.0	100.0
146	STREET AREA	0.	2	0.	350.0	3	100.0	250.0
147	STREET AREA	0.	2	100.0	350.0	3	200.0	250.0
148	STREET AREA	0.	2	100.0	250.0	4	200.0	350.0
149	STREET AREA	0.	2	100.0	350.0	3	300.0	250.0
150	STREET AREA	0.	2	100.0	250.0	4	300.0	350.0
151	STREET AREA	0.	2	100.0	350.0	3	400.0	250.0
152	STREET AREA	0.	2	100.0	250.0	4	400.0	350.0
153	STREET AREA	0.	2	100.0	350.0	3	500.0	250.0
154	STREET AREA	0.	2	100.0	250.0	4	500.0	350.0
155	STREET AREA	0.	2	100.0	350.0	3	600.0	250.0
156	STREET AREA	0.	2	100.0	250.0	4	600.0	350.0
157	STREET AREA	0.	2	100.0	350.0	3	700.0	250.0
158	STREET AREA	0.	2	100.0	250.0	4	700.0	350.0
159	STREET AREA	0.	2	100.0	350.0	3	800.0	250.0
160	STREET AREA	0.	2	100.0	250.0	4	800.0	350.0
161	STREET AREA	0.	2	100.0	350.0	3	900.0	250.0
						4	900.0	350.0
						3	1000.0	250.0
						4	1000.0	350.0
						3	1100.0	250.0
						4	1100.0	350.0
						3	600.0	500.0
						4	600.0	600.0
						3	600.0	450.0
						4	600.0	500.0
						3	600.0	350.0
						4	600.0	450.0
						3	600.0	150.0
						4	600.0	250.0
						3	600.0	100.0
						4	600.0	150.0
						3	600.0	0.
						4	600.0	100.0

Table 12 (cont.)

ORIGIN --- ORIGIN A 200 FT. WEST OF INTRSECTN. X = 350.0
Y = 300.0
H = 3.0

(NOTE-DIMENSIONS IN FEET UNLESS OTHERWISE INDICATED)

RESULTS OF COMPUTATIONS

AREA	ATT.	CONST.	DOSE	DOSE/DINF	J	CODE	LAYER TYPE	THICKNESS	SLANT
1	4.8873E-04	2.5187E-05	0.0001		1	AR	VERTICAL	340.0000	353.4037
					2	BR	VERTICAL	1.0000	1.0394
					31	WD	HORIZONTAL	1.0000	3.6662
2	7.5605E-06	5.5676E-08	0.0000		1	AR	VERTICAL	320.0000	320.0140
					2	BR	VERTICAL	2.0000	2.0001
3	5.2443E-04	1.6428E-05	0.0001		1	AR	VERTICAL	297.0000	305.2910
					2	BR	VERTICAL	1.0000	1.0279
					31	WD	HORIZONTAL	1.0000	4.3202
4	8.5675E-05	7.7344E-08	0.0000		1	AR	VERTICAL	289.0000	289.0159
					2	BR	VERTICAL	2.0000	2.0001
5	1.6140E-04	9.3543E-06	0.0000		1	AR	VERTICAL	258.0000	271.8301
					2	CN	VERTICAL	1.0000	1.0336
					31	WD	HORIZONTAL	1.0000	3.1755
6	2.2182E-10	2.6205E-12	0.0000		1	AR	VERTICAL	239.0000	239.0189
					2	BR	VERTICAL	4.0000	4.0003
7	7.6127E-05	3.8969E-06	0.0000		1	AR	VERTICAL	257.0000	307.1628
					2	CN	VERTICAL	1.0000	1.1952
					31	WD	HORIZONTAL	1.0000	1.6259
8	1.0888E-05	1.5416E-07	0.0000		1	AR	VERTICAL	212.0000	212.0212
					2	BR	VERTICAL	2.0000	2.0002
9	9.7515E-07	5.6132E-08	0.0000		1	AR	VERTICAL	203.0000	207.9647
					2	BR	VERTICAL	2.0000	2.0489
					31	WD	HORIZONTAL	2.0000	9.2082
10	1.1262E-05	1.7323E-07	0.0000		1	AR	VERTICAL	202.0000	202.0225
					2	BR	VERTICAL	2.0000	2.0002
11	2.7900E-10	1.2981E-11	0.0000		1	AR	VERTICAL	203.0000	203.2054
					2	BR	VERTICAL	3.0000	3.0030
					31	WD	HORIZONTAL	1.0000	22.2447

Table 12 (Cont.)

12	1.1319E-05	1.7533E-07	0.0000	1	AR	VERTICAL	200.5000	200.5225
				2	BR	VERTICAL	2.0000	2.0002
13	2.5106E-09	1.8468E-10	0.0000	1	AR	VERTICAL	205.0000	207.7446
				2	BR	VERTICAL	2.0000	2.0268
				3	CN	VERTICAL	1.0000	1.0134
				31	WD	HORIZONTAL	1.0000	6.1724
14	2.4292E-10	3.4392E-12	0.0000	1	AR	VERTICAL	212.0000	212.0212
				2	BR	VERTICAL	4.0000	4.0004
15	2.3957E-04	1.7772E-05	0.0001	1	AR	VERTICAL	248.0000	282.2215
				2	ST	VERTICAL	1.0000	1.1380
				31	WD	HORIZONTAL	1.0000	2.0251
16	3.5152E-01	1.0431E-02	0.0412	1	AR	VERTICAL	309.0000	309.0146
17	8.0892E-06	3.7449E-08	0.0000	1	AR	VERTICAL	300.0000	300.0150
				2	BR	VERTICAL	2.0000	2.0001
18	9.3226E-06	2.5446E-07	0.0000	1	AR	VERTICAL	258.0000	258.0174
				2	BR	VERTICAL	2.0000	2.0001
19	1.1886E-05	1.0013E-06	0.0000	1	AR	VERTICAL	186.0000	186.0242
				2	BR	VERTICAL	2.0000	2.0003
20	1.3060E-05	9.9830E-07	0.0000	1	AR	VERTICAL	158.0000	158.0284
				2	BR	VERTICAL	2.0000	2.0004
21	1.3192E-05	1.9183E-07	0.0000	1	AR	VERTICAL	155.0000	155.0289
				2	BR	VERTICAL	2.0000	2.0004
22	1.3415E-05	1.6435E-06	0.0000	1	AR	VERTICAL	150.0000	150.0300
				2	BR	VERTICAL	2.0000	2.0004
23	1.3192E-05	1.9183E-07	0.0000	1	AR	VERTICAL	155.0000	155.0289
				2	BR	VERTICAL	2.0000	2.0004
24	1.3016E-05	6.9268E-07	0.0000	1	AR	VERTICAL	159.0000	159.0286
				2	BR	VERTICAL	2.0000	2.0004
25	2.7504E-10	3.2720E-12	0.0000	1	AR	VERTICAL	175.0000	175.0257
				2	BR	VERTICAL	4.0000	4.0006
26	1.2128E-05	6.1724E-07	0.0000	1	AR	VERTICAL	180.0000	180.0249
				2	BR	VERTICAL	2.0000	2.0003
27	5.9738E-04	3.9791E-05	0.0002	1	AR	VERTICAL	286.0000	296.1836
				2	BR	VERTICAL	1.0000	1.0426
				31	WD	HORIZONTAL	1.0000	3.5344

Table 12 (Cont.)

28	4.0794E-01	4.7216E-03	0.0187	1	AR	VERTICAL	265.0000	265.0170
29	1.4986E-04	9.1524E-06	0.0000	1	AR	VERTICAL	216.0000	240.1963
				2	CN	VERTICAL	1.0000	1.1120
				31	WD	HORIZONTAL	1.0000	2.2862
30	6.6623E-01	1.8240E-01	0.7207	1	AR	VERTICAL	120.0000	120.0370
31	5.4962E-04	2.0352E-04	0.0008	1	AR	VERTICAL	72.0000	72.2809
				2	BR	VERTICAL	1.0000	1.0081
				31	WD	HORIZONTAL	1.0000	7.9201
32	8.0239E-01	7.3385E-02	0.2900	1	AR	VERTICAL	65.0000	65.0713
33	1.3374E-03	1.1473E-03	0.0045	1	AR	VERTICAL	55.0000	59.6541
				2	BR	VERTICAL	1.0000	1.0646
				31	WD	HORIZONTAL	1.0000	2.2824
34	8.0239E-01	7.3385E-02	0.2900	1	AR	VERTICAL	65.0000	65.0713
35	5.6267E-05	9.1129E-06	0.0000	1	AR	VERTICAL	115.0000	190.0042
				2	BR	VERTICAL	1.0000	1.6522
				31	WD	HORIZONTAL	1.0000	1.2562
36	7.0327E-01	3.6050E-02	0.1424	1	AR	VERTICAL	104.0000	104.0441
37	7.0519E-04	1.0987E-04	0.0004	1	AR	VERTICAL	130.0000	152.7641
				2	BR	VERTICAL	1.0000	1.1751
				31	WD	HORIZONTAL	1.0000	1.9041
38	2.6863E-04	1.2433E-05	0.0000	1	AR	VERTICAL	308.0000	323.0145
				2	ST	VERTICAL	1.0000	1.0487
				31	WD	HORIZONTAL	1.0000	3.3185
39	3.8384E-01	3.9073E-03	0.0154	1	AR	VERTICAL	283.0000	283.0157
40	1.1900E-04	7.7352E-06	0.0000	1	AR	VERTICAL	235.0000	287.2504
				2	CN	VERTICAL	1.0000	1.1265
				31	WD	HORIZONTAL	1.0000	2.1722
41	4.8313E-01	7.9848E-03	0.0315	1	AR	VERTICAL	215.0000	215.0208
42	4.6691E-04	1.0592E-04	0.0004	1	AR	VERTICAL	134.0000	138.2499
				2	ST	VERTICAL	1.0000	1.0317
				31	WD	HORIZONTAL	1.0000	4.0643
43	6.6623E-01	2.7394E-02	0.1082	1	AR	VERTICAL	120.0000	120.0370
44	5.9559E-04	1.4146E-04	0.0006	1	AR	VERTICAL	120.0000	120.0370

Table 12 (Cont.)

45	1 2 31	7.8363E-01	6.3997E-02	0.2529	AR	VERTICAL	95.0000	117.6034
					BR	VERTICAL	1.0000	1.2360
					WD	HORIZONTAL	1.0000	1.6963
46	1 2 31	9.6465E-04	5.2273E-04	0.0021	AR	VERTICAL	72.0000	72.0646
					BR	VERTICAL	51.0000	51.6196
					WD	HORIZONTAL	1.0000	1.0161
47	1 2 31	8.4411E-01	6.5007E-01	2.4895	AR	VERTICAL	50.0000	50.0899
					BR	VERTICAL	51.0000	51.7883
					WD	HORIZONTAL	1.0000	1.0155
48	1 2 31	9.4358E-04	3.3856E-04	0.0013	AR	VERTICAL	51.0000	51.7883
					BR	VERTICAL	1.0000	1.0155
					WD	HORIZONTAL	1.0000	5.7532
49	1 2	1.8305E-06	3.8678E-08	0.0000	AR	VERTICAL	326.0000	326.0136
					ST	VERTICAL	2.0000	2.0001
50	1 2 3	4.2125E-11	1.7560E-13	0.0000	AR	VERTICAL	317.0000	317.0141
					ST	VERTICAL	2.0000	2.0001
					BR	VERTICAL	2.0000	2.0001
51	1 2 3	4.9868E-11	1.5074E-12	0.0000	AR	VERTICAL	267.0000	267.0169
					ST	VERTICAL	2.0000	2.0001
					BR	VERTICAL	2.0000	2.0001
52	1 2 3	5.1231E-11	3.1160E-13	0.0000	AR	VERTICAL	259.0000	259.0175
					ST	VERTICAL	2.0000	2.0001
					BR	VERTICAL	2.0000	2.0001
53	1 2	1.1648E-05	8.5564E-07	0.0000	AR	VERTICAL	192.0000	192.0234
					BR	VERTICAL	2.0000	2.0002
54	1 2	2.6599E-10	2.8544E-12	0.0000	AR	VERTICAL	185.0000	185.0241
					BR	VERTICAL	4.0000	4.0000
55	1 2	1.2929E-05	8.0590E-07	0.0000	AR	VERTICAL	161.0000	161.0278
					BR	VERTICAL	2.0000	2.0003
56	1 2	1.3104E-05	1.8466E-07	0.0000	AR	VERTICAL	157.0000	157.0263
					BR	VERTICAL	2.0000	2.0004
57	1 2	1.2415E-05	1.0157E-06	0.0000	AR	VERTICAL	150.0000	150.0300
					BR	VERTICAL	2.0000	2.0004
58	1 2	6.0194E-01	1.1574E-01	0.4573	AR	VERTICAL	150.0000	150.0300
					BR	VERTICAL	282.0000	282.0155
					WD	VERTICAL	2.0000	2.0001
59	1 2	8.5966E-06	8.8823E-07	0.0000	AR	VERTICAL	150.0000	150.0300
					BR	VERTICAL	282.0000	282.0155
					WD	VERTICAL	2.0000	2.0001

Table 12 (Cont.)

60	1.4029E-10	1.5701E-11	0.0000	1 2 31	AR BR WD	VERTICAL VERTICAL HORIZONTAL	225.0000 3.0000 1.0000	225.1822 3.0024 24.8653
61	1.0634E-05	1.4287E-07	0.0000	1 2	AR BR	VERTICAL VERTICAL	219.0000 2.0000	219.0205 2.0002
62	1.3160E-07	1.1315E-08	0.0000	1 2 31	AR CN BR WD	VERTICAL VERTICAL VERTICAL HORIZONTAL	205.0000 1.0000 1.0000 2.0000	207.7112 1.0132 1.0132 12.5189
63	1.1262E-05	1.7323E-07	0.0000	1 2	AR BR	VERTICAL VERTICAL	202.0000 2.0000	202.0225 2.0002
64	2.0395E-01	1.4957E-02	0.0591	1 31	AR WD	VERTICAL HORIZONTAL	208.0000 1.0000	216.2625 3.6485
65	1.1262E-05	1.7145E-07	0.0000	1 2	AR BR	VERTICAL VERTICAL	202.0000 2.0000	202.0222 2.0002
66	2.3238E-05	1.0214E-06	0.0000	1 2 31	AR BR WD	VERTICAL VERTICAL HORIZONTAL	204.0000 1.0000 2.0000	205.0784 1.0053 19.5275
67	1.0962E-05	1.5520E-07	0.0000	1 2	AR BR	VERTICAL VERTICAL	210.0000 2.0000	210.0210 2.0002
68	2.0595E-09	1.8093E-10	0.0000	1 2 3 31	AR ST BR WD	VERTICAL VERTICAL VERTICAL HORIZONTAL	216.0000 1.0000 2.0000 1.0000	217.0240 1.0047 2.0095 10.3061
69	9.0347E-30	1.0687E-30	0.0000	1 2 3 31	AR CN BR CN	VERTICAL VERTICAL VERTICAL HORIZONTAL	326.0000 1.0000 2.0000 1.0000	329.2045 1.0098 2.0197 7.1845
70	5.3819E-12	1.5811E-14	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	540.0000 2.0000 2.0000	540.0084 2.0000 2.0000
71	5.4746E-16	7.1042E-18	0.0000	1 2 3 4 31	AR BR CN ST WD	VERTICAL VERTICAL VERTICAL VERTICAL HORIZONTAL	557.0000 2.0000 2.0000 1.0000 2.0000	567.1352 2.0364 2.0364 1.0182 10.6245
72	1.4684E-12	1.0917E-14	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	595.0000 2.0000 2.0000	595.0076 2.0000 2.0000
76	6.3109E-06	1.5020E-07	0.0000					

Table 12 (cont.)

77	7.4338E-06	2.9490E-08	0.0000	1 2	AR BR	VERTICAL VERTICAL	292.0000 2.0000	292.0155 2.0001
78	7.1624E-06	1.2297E-07	0.0000	1 2	AR BR	VERTICAL VERTICAL	325.0000 2.0000	325.0137 2.0001
79	9.2128E-12	2.7439E-14	0.0000	1 2	AR BR	VERTICAL VERTICAL	336.0000 2.0000	336.0134 2.0001
80	8.9368E-12	1.1681E-13	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	381.0000 2.0000 2.0000	381.0118 2.0001 2.0001
81	1.1419E-17	2.6261E-20	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	390.0000 2.0000 2.0000	390.0115 2.0001 2.0001
82	1.1040E-17	1.3290E-19	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	437.0000 2.0000 4.0000	437.0103 2.0000 4.0001
83	4.0776E-13	7.1550E-16	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	447.0000 2.0000 4.0000	447.0101 2.0000 4.0001
84	8.8623E-18	4.3441E-20	0.0000	1 2	AR CN	VERTICAL VERTICAL	504.0000 4.0000	504.0090 4.0001
85	8.0619E-18	1.2280E-20	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	512.0000 2.0000 4.0000	512.0088 2.0000 4.0001
86	7.8203E-18	5.3935E-20	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	540.0000 2.0000 4.0000	540.0083 2.0000 4.0001
93	9.3125E-05	3.3727E-06	0.0000	1 2 3	AR BR CN	VERTICAL VERTICAL VERTICAL	549.0000 2.0000 4.0000	549.0081 2.0000 4.0001
94	3.6982E-01	3.5398E-03	0.0140	1	AR	VERTICAL	294.0000	294.0153
95	1.0107E-04	3.4755E-06	0.0000	1 2 31	AR CN WD	VERTICAL VERTICAL HORIZONTAL	293.0000 1.0000 1.0000	334.8237 1.0000 1.1427
96	3.0188E-01	2.0626E-03	0.0061	1	AR	VERTICAL	354.0000	354.0127

Table 12 (cont.)

97	4.1566E-04	1.1612E-05	0.0000	1 2 31	AR BR WD	VERTICAL VERTICAL HORIZONTAL	375.0000 1.0000 1.0000	387.0816 1.0322 4.0340
98	2.4809E-01	1.2663E-03	0.0050	1	AR	VERTICAL	412.0000	412.0109
99	2.7915E-04	7.1366E-06	0.0000	1 2 31	AR BR WD	VERTICAL VERTICAL HORIZONTAL	430.0000 1.0000 1.0000	437.8139 1.0182 5.2167
100	1.9380E-01	7.9555E-04	0.0029	1	AR	VERTICAL	455.0000	485.0094
101	6.1212E-05	5.7725E-07	0.0000	1 2 31	AR CN WD	VERTICAL VERTICAL HORIZONTAL	523.0000 1.0000 1.0000	555.7446 1.0426 2.9970
102	1.6984E-01	5.5363E-04	0.0022	1	AR	VERTICAL	524.0000	524.0086
103	5.2422E-05	7.3694E-07	0.0000	1 2 31	AR CN WD	VERTICAL VERTICAL HORIZONTAL	547.0000 1.0000 1.0000	560.0550 1.0239 4.6586
104	1.3958E-01	3.6910E-04	0.0015	1	AR	VERTICAL	582.0000	582.0077
105	1.4284E-04	2.2682E-06	0.0000	1 2 31	AR BR WD	VERTICAL VERTICAL HORIZONTAL	602.0000 1.0000 1.0000	611.3920 2.0156 5.7272
110	2.7757E-04	2.5402E-05	0.0001	1 2 31	AR ST WD	VERTICAL VERTICAL HORIZONTAL	262.0000 1.0000 1.0000	268.4681 1.0247 4.5832
111	3.0086E-01	2.0558E-03	0.0081	1	AR	VERTICAL	355.0000	355.0128
112	1.7128E-02	5.0127E-04	0.0020	1 2 31	AR WD WD	VERTICAL VERTICAL HORIZONTAL	362.0000 1.0000 1.0000	363.4891 1.0041 11.0591
113	2.6642E-01	1.2577E-03	0.0050	1	AR	VERTICAL	414.0000	414.0109
114	8.2580E-05	2.9341E-06	0.0000	1 2 31	AR CN WD	VERTICAL VERTICAL HORIZONTAL	435.0000 1.0000 1.0000	448.2034 1.0304 4.1505
115	1.7628E-01	5.9831E-04	0.0024	1	AR	VERTICAL	512.0000	512.0088
116	3.9654E-05	8.9827E-07	0.0000	1 2 31	AR CN WD	VERTICAL VERTICAL HORIZONTAL	530.0000 1.0000 1.0000	536.3332 1.0119 6.5264

Table 12 (Cont.)

121	3.7486E-01	1.4674E-02	0.0580	1	AR	VERTICAL	290.0000	290.0153
122	1.5199E-06	4.5268E-09	0.0000	1	AR	VERTICAL	381.0000	381.0118
				2	ST	VERTICAL	2.0000	2.0001
123	1.4744E-06	1.9272E-08	0.0000	1	AR	VERTICAL	390.0000	390.0115
				2	ST	VERTICAL	2.0000	2.0001
124	1.2577E-06	2.8923E-09	0.0000	1	AR	VERTICAL	437.0000	437.0103
				2	ST	VERTICAL	2.0000	2.0000
125	1.2159E-06	2.0800E-08	0.0000	1	AR	VERTICAL	447.0000	447.0101
				2	ST	VERTICAL	2.0000	2.0000
126	5.7175E-07	9.0152E-10	0.0000	1	AR	VERTICAL	531.0000	531.0085
				2	ST	VERTICAL	2.0000	2.0000
				3	WD	VERTICAL	2.0000	2.0000
127	5.4901E-07	5.9728E-09	0.0000	1	AR	VERTICAL	543.0000	543.0083
				2	ST	VERTICAL	2.0000	2.0000
				3	WD	VERTICAL	2.0000	2.0000
132	4.3979E-04	2.1855E-05	0.0001	1	AR	VERTICAL	328.0000	335.5311
				2	BR	VERTICAL	1.0000	1.0230
				31	WD	HORIZONTAL	1.0000	4.7465
133	2.7182E-01	1.4549E-03	0.0057	1	AR	VERTICAL	385.0000	385.0116
134	1.4879E-04	4.7568E-06	0.0000	1	AR	VERTICAL	396.0000	396.5685
				2	BR	VERTICAL	1.0000	1.0085
				31	WD	HORIZONTAL	1.0000	8.8227
135	2.1378E-01	8.5024E-04	0.0034	1	AR	VERTICAL	450.0000	456.0099
136	3.4665E-05	8.3944E-07	0.0000	1	AR	VERTICAL	465.0000	466.1685
				2	BR	VERTICAL	1.0000	1.0025
				31	WD	HORIZONTAL	1.0000	14.1320
137	1.6643E-01	5.0486E-04	0.0020	1	AR	VERTICAL	530.0000	530.0085
138	6.2773E-10	1.1068E-11	0.0000	1	AR	VERTICAL	545.0000	559.3384
				2	BR	VERTICAL	1.0000	1.0186
				3	ST	VERTICAL	2.0000	2.0377
				31	WD	HORIZONTAL	1.0000	5.2255
139	7.6238E-07	1.9190E-09	0.0000	1	AR	VERTICAL	585.0000	585.0077
				2	ST	VERTICAL	2.0000	2.0000
140	5.6381E-10	1.0127E-11	0.0000	1	AR	VERTICAL	605.0000	610.5501
				2	ST	VERTICAL	2.0000	2.0345

Table 12
(Cont.)

TOTAL RELATIVE DOSE =	2.1103E C1
=	63.261 PER CENT OF BACKGROUND RADIATION